



Hazard Mitigation Funding
Opportunity Approach for
Coastal Resilience Projects
with Ecosystem Services
Methodology

Project reference: TCRMP Project number: 60615820

December 1, 2021

Hazard Mitigation Funding Opportunity Approach for Coastal Resilience Projects with Ecosystem Services Methodology

## Quality information

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# Introduction

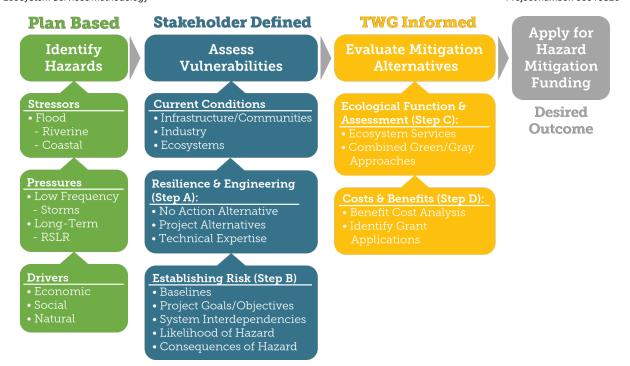
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This document supports the refinement and implementation of the Texas Coastal Resiliency Master Plan (TCRMP) by presenting a methodology for determining the benefits of incorporating ecosystem services and coastal resilience components into traditional hazard mitigation projects. To accomplish this, the GLO Planning Team formed an Ecosystem Services Technical Working Group (TWG) and developed an approach to qualitatively describe the benefits of ecosystem restoration projects as part of traditional Benefit Cost Analyses (BCAs) in general, such as those developed for federal grant opportunities. However, different opportunities may have different requirements for their BCAs, which should be reviewed in further detail by individuals utilizing this approach. The goal of this effort is to present a balanced approach that better integrates nature-based solutions and coastal resilience components into traditional hazard mitigation projects for the purpose of supporting project proponents in determining whether a project may be appropriate for hazard mitigation funding opportunities. By including these concepts in conventional methods and taking a more comprehensive approach to project benefit evaluation, the aim is to broaden the scope and technical reach of traditional hazard mitigation efforts, improving the net quality of the projects funded and designed in coastal hazard mitigation. Potential benefits include:

- An increase in the role that nature-based solutions currently play in project decisionmaking to approach hazard mitigation projects comprehensively with both ecological and structural components considered.
- A more streamlined approach to account for and secure project funding for projects that include ecosystem services and nature-based components.
- Better integration of the benefits of ecosystem services and coastal resilience components into traditional hazard mitigation projects.

The following framework summarizes the overall process. It should also be noted here that the project proponent is encouraged to develop a finance strategy plan to identify the timing of projects, relevant grant cycles, and the financial connectivity between selected projects in the areas intended for hazard mitigation. Many times, when looking at hazard mitigation, projects are viewed individually and not on a broader community wide scale. Particularly with the scale of nature-based solutions, if an overall strategy isn't developed related to addressing large-scale mitigation for the projects identified for the community, the success of the individual project may be lower than intended. In addition, to achieve the overall intended effect of system-wide resilience, identifying the intricacies of these roles in community planning provides a long-term vision to achieve mitigation across an entire ecosystem.



The TWG is composed of carefully selected experts from public agencies, private companies, and non-governmental organizations to work with the Planning Team to develop a framework to assist the GLO in understanding existing funding structure and creating an approach to evaluate the natural capital benefits to implementing infrastructure projects that incorporate ecosystem services (Figure 1-1). These benefits are associated with the ecological components of projects seeking federal grant funding, which typically require a planning-level BCA as part of the submitted application. Presently, there are limited metrics available to include these benefits into the required BCAs. This methodology:

- A. Provides an assessment to screen for projects potentially appropriate for hazard mitigation funding opportunities,
- B. Identifies and defines potential areas of risk along the Texas coast where projects might be most beneficial,
- C. Describes the benefits of the ecological components of the project through characterization of its main ecosystem service functions, and
- D. Identifies potential target hazard mitigation funding opportunities.

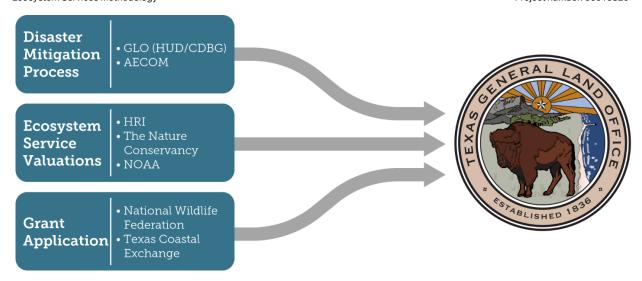


Figure 1-1. Primary Roles and Technical Expertise of Technical Working Group Participants

Throughout development of this methodology, the TWG has guided the Planning Team in an advisory capacity, providing expert insights and critiques. The TWG has directed the Planning Team on several objectives, including:

- Characterizing ecosystem services for the following habitats relative to the Texas coast:
  - Coastal Bottomland Forests
  - Mangroves
  - Seagrass
  - Coastal Wetlands
  - Coastal Prairies
  - Beaches and Dunes
  - Rookery Islands
- Determining best practices to value ecosystem services at a project-level along the Texas coast.
- Developing methods to incorporate ecosystem service benefits into BCAs for applicable projects.
- Identifying and implementing pilot project case studies to demonstrate effectiveness of the methodology.

Additionally, as the Planning Team met developmental goals along the way, meetings were held with the TWG to discuss progress and next steps. During these meetings the TWG aided the Planning Team in identifying how various ecological components can be incorporated into the BCA of traditional infrastructure-related projects. This was accomplished through a comprehensive assessment of BCA development to understand how data and metrics are used for infrastructure project BCAs, discussions on how to incorporate ecosystem services from coastal resilience projects as a component of traditional hazard mitigation BCAs, and the consideration of long-term resilience enhancements for projects that include nature-based solutions or components and implications of these enhancements for a project's BCA. The TWG also helped prepare a defensible approach for including ecosystem services in BCAs for traditional infrastructure projects with natural capital assets, as well as recommended approaches to achieving this via applications for project grants. During the final TWG meeting, results and findings of the enclosed methodology were summarized and an approach was

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recommended to secure concurrence among applicable state and federal agencies. Additionally, the TWG helped identify case studies that this approach could be applied to.

The remainder of this document details the methodology developed by the Planning Team in conjunction with the TWG. A memorandum was developed in 2018 for inclusion in the 2019 TCRMP which was intended to refine economic valuations of ecosystem services at the Resiliency Strategy level for the Texas coast. The 2018 TCRMP Ecosystem Services Technical Memorandum was used as a basis for the development of this methodology and is included in this document. Additionally, a literature review of ecosystem services data relevant to the Texas coast was performed and provided to the TWG at the beginning of the process. This was built upon the 2018 memo and details the current status of ecosystem services, their benefits, and techniques used to evaluate them as of April 2020. The literature review was used to inform and develop a 4-Step approach to navigating hazard mitigation funding opportunities for coastal resilience projects with ecosystem services. Each step will be discussed at length, which will include a description of the objective and purpose of the step, and how it relates to hazard mitigation funding.

# 2018 Texas Coastal Resiliency Master Plan Ecosystem Services Technical Memorandum

This memorandum was developed in 2018 to further refine the economic valuations of ecosystem services and build upon efforts used in previous iterations of the Texas Coastal Resiliency Master Plan (TCRMP). Results from this memorandum were used in the 2019 TCRMP and are considered the starting point for the development of this methodology.



## Memo

AECOM 3101 Wilson Boulevard Arlington VA, 22201 USA aecom.com

#### Project name:

Texas Coastal Resiliency Master Plan Phase II

Date:

July 5, 2018

Prepared by: Andrea Bohmholdt

The purpose of this memorandum is to build upon the previous effort during Phase 1 and further refine the economic valuations at the Resiliency Strategy level for the Texas coast. Refinements include reviewing the Phase 1 ecosystem services for possible updates based on existing literature, while considering regional or sub-regional characteristics that could change how the ecosystem services are represented at different locations along the coast.

The Texas coast is divided into four regions based on major bay systems and habitats. The first region, Sabine Pass to Galveston Bay extends from the mouth of Sabine River at the Texas-Louisiana border to the west side of Galveston Bay. The second region, Matagorda Bay includes the entire Matagorda Bay system from the Brazoria-Matagorda County line to the eastern edge of San Antonio Bay. The third region, Corpus Christi Bay extends from the San Antonio Bay to Baffin Bay. The fourth region, Padre Island stretches from the southern edge of Baffin Bay to the Texas-Mexico border.

The U.S. Army Corps of Engineers (USACE) defines three primary categories of coastal risk reduction: structural measures (such as levees and floodwalls), nonstructural measures (such as buy-outs and raising structures), and natural and nature-based features. Nature-based features are manmade and may mimic characteristics of natural features, such as habitat creation and restoration, wildlife, environmental, beach nourishment, and dune restoration. Ecosystem services related to existence, creation, and restoration of the following habitat types were considered: oyster reefs, coastal wetlands, bottomland forests, mangroves, coastal prairies, beaches and dunes, and seagrass.

The ecosystem services can be categorized as provisioning, regulating, supporting, and cultural services. Provisioning services may include food, raw materials, and medicinal resources that can be used by people. Regulating services are services provided by ecosystems that act as regulators, such as regulating air quality, water quality, moderating extreme events, erosion prevention, and biological control. Supporting services can also be described as the habitats that provide for flora and fauna to survive, such as food water, and shelter. Supporting services may also include the maintenance of genetic diversity. Cultural services can include the recreational value of the ecosystem, aesthetics, tourism, and the spiritual experience provided by the ecosystem.

The value of ecosystem services provided by habitats along the Texas coast is specific to the location and type of habitat and is highly context specific. This can make valuation difficult when comparing across different environmental conditions. The following sections provide estimated values for the Texas coast according to habitat type and conditions. These estimates are conservative values intended as high-level estimates and are not meant to represent the full value of ecosystem services for the Texas coast. It is expected that there is a high level of uncertainty associated with these estimates and it is recommended to conduct an uncertainty

analysis when applying these values. Because the values estimated are not precise, all values are rounded to the nearest ten or hundred.

A benefits transfer approach was employed using meta-analyses on a national or global scale except when studies specific to the Texas coast or the Gulf Coast were available. Although there are a limited number of ecosystem services studies conducted in Texas and neighboring states with similar habitats, the average values from these studies were used when possible to estimate the value of ecosystem services for the Texas coast. The estimated benefits transferred from other studies were adapted to the Texas coast and adjusted for inflation to 2018 dollars. Although some habitats may be difficult to distinguish, it is important to designate each acre (or fraction of an acre) as a specific habitat type to prevent double-counting benefits.

## **Oyster Reefs**

In addition to the traditional provisioning services from oyster harvests, oyster reefs provide regulating, supporting, and cultural services. Regulating services include nutrient control and shoreline erosion control. Supporting services include fishery habitat and estuarine protection. Cultural services include recreation, historical significance, and non-use values.

#### **Provisioning**

Prior to Hurricane Ike, over half of the public oyster reefs in Texas were found in Galveston Bay, accounting for 80 percent or more of Texas' annual commercial oyster harvest (NOAA, 2007). Using the 2000 values from the Texas Parks and Wildlife Department, the estimated statewide average annual value is 243.2 pounds of oyster meat per harvestable acre (Robinson, 2014). The average value is used because a full range of estimates were not available. Using the National Marine Fisheries Service Annual Commercial Landing Statistics database, eastern oyster landings in Texas were valued at \$5.48 per pound of meat on average in 2016. The market value of oyster harvests can be calculated by subtracting the costs of harvesting from the commercial dockside value. The maximum ratio of revenue to cost from the 18-year period for dredging observed in Wieland's study was 1.5 (2008). Applying the same cost ratio and inflating values to 2018 dollars results in an estimated net value of about \$500 per acre or \$1,100 per hectare per year for provisioning services.

The true value of oyster harvest is likely much higher than what is reported as commercial harvest value because there is additional value made through the resale of oysters that can be added to the initial dock value. However, it is difficult to assess the full value due to the tremendous variability of harvest from reef to reef, bay to bay, and season to season. Different reefs and bays may have an average value per pound of meat, per acre of oyster reef, or per bag of whole oysters that is reported different depending on the season, location, or current market price. Additionally, there is a chance of transactions occurring from recreational and subsistence harvesting that is not reported.

## Regulating

Regulating services include nutrient control and shoreline erosion control. Oyster reefs can improve water quality by removing chlorophyll, reducing turbidity, denitrification, increasing benthic algal or pseudofecal production, and bacterial biomass removal. As oysters grow, both nitrogen and carbon are assimilated into their tissue and shell. When oysters are harvested, there is a removal of nitrogen and carbon from the water column. However, oysters also release carbon dioxide and other greenhouse gases, such as methane from gut bacteria. Considerable

uncertainty remains whether oyster reefs are sources or sinks of atmospheric carbon dioxide (Fodrie et al. 2017). As a result, carbon sequestration and greenhouse gases from oyster reefs were not monetized.

#### **Nutrient Control**

Nutrient pollution form excess nitrogen in the waterways leads to harmful algae blooms and increases the amount of organic carbon within a water body which depletes the oxygen level (eutrophication) and lead to dead zones. Harmful algae blooms can impact tourism, recreation, commercial fishing, property values, and human health (EPA, 2015). Oysters can process nitrogen compounds into harmless nitrogen gas. Considering three studies conducted in Mission Aransas, Texas, Mobile Bay, Alabama, and North Carolina, the rate of nitrogen removal from oyster reefs ranges from 17 to 915 pounds of nitrogen per acre, per year; on average it is estimated that oyster reefs can remove 276 pounds of nitrogen per acre, per year (Beseres Pollack et al, 2013 and Kroeger, 2012).

Nitrogen removal is monetized using the marginal price for nitrogen mitigation estimated by Ribaudo et al. (2005). The study utilized the U.S. Agricultural Sector Mathematical Programming model to explore the potential for nitrogen credit trading in the Mississippi Basin. Fertilizer management by farmers was the least expensive option for nitrogen management and is used as a shadow price to value nitrogen removal. The marginal cost ranges from \$59 to \$273 per pound of nitrogen removed in 2018 dollars. This is supported by the more recent Van Houtven et al. study (2012) that valued agricultural and urban stormwater best management practices between \$100 and \$300 per pound of nitrogen removal. Nutrient control from oyster reefs along the Texas coast can be valued between \$1,000 and \$274,500 per acre per year or \$2,500 to \$678,300 per hectare per year. Using the average value of \$166 per pound of nitrogen removed, oyster reefs can be valued at \$45,800 per acre per year or \$113,200 per hectare per year for regulating services.

#### **Erosion Control**

In tidal and subtidal environments, oyster reefs stabilize sediments and deflect wave energy, providing natural protection against shoreline erosion and loss of shoreline (Henderson, 2003). Decreasing coastal property values has been attributed to loss of shoreline and shoreline erosion. In areas where engineered systems would traditionally be built, the value of the oyster reef is equivalent to the value of those systems for the erosion protection services. However, if the oyster reef is located in an area where erosion is not a concern, then the erosion protection value of the oyster reef is may be evaluated as very low or zero because the services are not needed and are not marketable (Grabowski, 2012).

In locations where property owners would otherwise use engineered systems, the cost of bulkheads and rock revetments ranges from \$600 to \$840 per linear meter. Assuming that 5 square meters (m²) is required to protect 1 meter of shoreline and that oyster reefs have an average width of 5 meters, the erosion value of oyster reef ranges from \$1.2 million to \$1.7 million per hectare (present value). To estimate the annual flow of benefits, it is assumed that these engineered systems have a 20-year life span. Using a 3 percent discount rate, the annual value ranges from \$81,000 to \$113,400 per hectare or \$32,800 to \$45,900 per acre. Using the average cost of bulkheads and rock revetments as a proxy for the erosion protection services from oyster reefs results in an average annual value for erosion control of \$39,000 per acre per year or \$93,500 per hectare per year (Grabowski, 2012).

#### **Supporting**

Oyster reefs provide non-market ecosystem services, such as creating a diverse habitat for juvenile fish and mobile crustaceans and refuge from predators. This provision for forage species can enhance production of economically important fishery stocks (Coen et al. 1999; Breitburg et al. 2000; Harding and Mann 2001; Peterson et al. 2003; Tolley and Volety 2005). A study by Zimmerman et al. found several economically valuable species such as grass shrimp, blue crab, stone crab, and several game fish species while assessing an oyster reef habitat in West Bay, Galveston, Texas (1989). However, the landscape setting of the oyster reef impacts the provision of its ecosystem services. For example, oyster reefs located on mud flats can boost the abundance of juvenile fish, whereas oyster reefs at the edge of salt marsh and seagrass habitat can have no effect on juvenile fish (Grabowski et al. 2005).

The additional production of fish and crab from five studies conducted along the Gulf Coast (including West Bay, Texas) range from 1,531.6 to 2,640.8 pounds of production per year (Kroeger, 2012; Peterson, 2003; Plunket, 2004; Scyphers, 2011; Stunz, 2010). Using the National Marine Fisheries Service Annual Commercial Landing Statistics database, the average value of landings for all species combined was calculated to be \$2.54 per pound in 2016, inflated to \$2.64 in 2018 dollars. The value of supporting services from oyster reefs is estimated to range from \$4,000 to \$7,000 per acre per year or \$10,000 to \$17,200 per hectare per year. The average value of supporting services is estimated to be \$5,500 per acre per year or \$13,600 per hectare per year.

#### **Cultural Services**

Cultural services include recreational and non-use cultural values.

#### Recreation

Oyster reefs can enhance recreational fishing and diving by attracting fish, increasing both the number of fish and biodiversity of the area. A survey of recreational anglers fishing over oyster reefs off the coast of Louisiana found that anglers were willing to pay an average of \$18 per person per year to maintain the right to fish over oyster reefs (Henderson and O'Neil, 2003). Based on the 2000 Census, the median household income in Louisiana was 32,566 and the median household income in Texas was 39,927. The willingness to pay value was adjusted to reflect the higher income level in Texas, resulting in an average value of \$22 per person per year for recreational fishing. To apply this value, the estimated number of recreational anglers for a particular oyster reef would be multiplied by \$22 to obtain the annual recreational value.

#### **Cultural Value**

People may value the presence of oyster reefs even if they have not or will not directly benefit from the reefs. Non-use values may include the bequest value, option value, or existence value. Hicks found that a 10-year, 1,000 acre oyster reef restoration project in the Chesapeake Bay had a non-use value of at least \$115 million to the Chesapeake population (2004). Because cultural/non-use services found in existing literature may overlap with other monetized services, cultural/non-use services were not monetized.

## **Application of Monetized Values for Oyster Reefs**

While the values estimated are good proxies, the full value of oyster reefs is likely underestimated. **Table 2-1** displays the monetized values for oyster reefs and a description of when they are applicable. Unless the oyster reef is severely degraded, the provisioning value

and nutrient control value should apply. Erosion protection services from oyster reefs only apply to locations where property owners would otherwise use engineered systems.

Supporting services are only applicable for oyster reefs located on mud flats, not oyster reefs at the edge of salt marsh and seagrass habitat, which can have no effect on juvenile fish.

The recreational value of oyster reefs can be applied by multiplying the value of \$22 per person per year by the number of estimated annual recreational fishermen.

**Average Average Ecosystem Annual Value Annual Value Description** Service per Acre per Hectare **Provisioning** \$500 \$1,100 Applies to healthy oyster reefs **Nutrient Control** \$45,800 \$113,200 Applies to healthy oyster reefs Applies to locations where property owners would otherwise use engineered **Erosion Control** \$39,000 \$96,500 systems Applies to oyster reefs located on mud Supporting \$13,600 flats, not oyster reefs at the edge of salt \$5,500 Services marsh and seagrass habitat

N/A \$22 per person recreating per year

**Table 2-1: Oyster Reef Summary** 

Note: All values rounded to the nearest hundred.

N/A

## **Coastal Wetlands**

Recreational

Coastal wetlands can also be referred to as coastal marshes or tidal wetlands. Wetlands are areas where water covers the soil, or is present either at or near the surface of the soil all year or for varying periods of time during the year, including during the growing season. The prolonged presence of water creates conditions that favor the growth of specially adapted plants and promote the development of characteristic wetland soils. Tidal wetlands are found along the Gulf coasts and are closely linked to estuaries where sea water mixes with fresh water to form an environment of varying salinities (EPA, 2018).

Provisioning from coastal wetlands includes the market value from the production of brown shrimp, white shrimp, and blue crabs. Coastal wetlands regulating services include storm protection, water quality, and carbon sequestration. Supporting services are limited to the value of the habitat. Cultural services include recreation, biodiversity, and aesthetics.

## **Provisioning**

Many studies have shown a link between shrimp growth, survival, and reproduction and availability of coastal wetland habitat (Engle, 2001). Shrimp larvae depend on marshland for habitat before growing large enough to move into open water. Minello et al (2008) examined the differences between crustacean growth and survival in coastal wetlands versus the open ocean in Galveston Bay and found that the marshes could support 3, 2.2, and 4.2 times the standing crop number in open water for brown shrimp, white shrimp, and blue crabs respectively. The standing crop refers to the weight of these organisms in an area at a given time. Production values were estimated to be 128 kg/ha for brown shrimp, 109 kg/ha for white shrimp, and 170 kg/ha for blue crabs (Minello et al, 2008).

Using the National Marine Fisheries Service Annual Commercial Landing Statistics database, the average value of landings in Texas for each species in 2016 was inflated to 2018 dollars and then multiplied by the production value for each species. The value of provisioning services from coastal wetlands for brown shrimp, white shrimp, and blue crabs is estimated to be \$4,500 per acre per year or \$11,100 per hectare per year.

#### Regulating

Coastal wetlands regulating services include storm protection, water filtration, nutrient control, and carbon sequestration.

#### **Storm Protection**

Coastal wetlands can provide a buffer between hurricane storm surge and coastal infrastructure by dissipating wave energy and attenuating storm surge. Costanza et al (2008) estimated that the average value of hurricane storm hazard risk reduction in Texas is \$6,700 per acre per year or \$16,600 per hectare per year (inflated to 2018 dollars). This value applies to coastal wetlands that are near infrastructure at risk for flood damage from potential hurricanes.

#### **Water Filtration**

Wetlands filter the water runoff from the land and reduce sediment and chemicals before the runoff enters the open water. The water filtration value for coastal wetlands is based on the meta-analysis performed by Woodward and Wui (2001) and a study by Wilson (2008) and is the national value supported by the Federal Emergency Management Agency for assessing wetland benefits. The water filtration services provided by coastal wetlands are valued at \$800 per acre per year or \$2,000 per hectare per year (in 2018 dollars).

#### **Nutrient Control**

Wetlands are effective for removing nitrogen by the process of nitrification and denitrification. Phosphorus is removed by the process of adsorption to the ions of metals. The value for nutrient control services from coastal wetlands is based on the Jenkins et al (2010) study conducted in the Mississippi Alluvial Valley and is the national value supported by the Federal Emergency Management Agency for assessing wetland benefits. The nutrient control services provided by coastal wetlands are valued at \$600 per acre per year or \$1,500 per hectare per year (in 2018 dollars).

## **Carbon Sequestration**

Coastal wetlands can sequester carbon in living biomass, in non-living biomass, and underneath marsh sediment. Carbon sequestration in salt marshes varies considerably and is primarily dependent on sedimentation rates and flooding frequency (Chmura et al. 2003). Low marsh is characterized by marsh that is subject to regular flooding by the tide (at least once a day), whereas high marsh is only irregularly flooded by tides and may go for extended periods without flooding. The average yearly net carbon sequestration for dominated low marsh was calculated to be 60,240 kg C per hectare per year and 57,020 kg C per hectare per year for dominated high marsh for sites in Louisiana that are very similar to the Texas coast (Feagin et al., 2010).

These rates were converted to pounds of carbon dioxide per hectare per year and then monetized using the 2018 value for the social cost of carbon developed by the Federal Interagency Working Group on Social Cost of Carbon. The value for carbon sequestration ranges from \$4,500 to \$4,700 per acre per year or \$11,100 to \$11,700 per hectare per year.

Because the low marsh and high marsh sequestration rates are very close, the average value was used to estimate the carbon sequestration value from coastal wetlands. The average carbon sequestration value is \$4,600 per acre per year or \$\$11,400 per hectare per year.

#### **Supporting**

More than one-third of the threatened and endangered species in the United States live only in wetlands and nearly half use wetlands at some point in their lives (EPA, 2018). Many other plants and animals depend on wetlands for food, shelter, and breeding grounds.

#### **Habitat**

The habitat value for coastal wetlands is based on the meta-analysis performed by Woodward and Wui (2001) and is the national value supported by the Federal Emergency Management Agency for assessing wetland benefits. The water quality services provided by coastal wetlands are valued at \$200 per acre per year or \$500 per hectare per year (in 2018 dollars).

## **Biodiversity**

Wetlands are among the most productive ecosystems in the world, comparable to rain forests and coral reefs (EPA, 2018). The biodiversity value for coastal wetlands is based on the meta-analysis performed by Schuyt and Brander (2004) and is the national value supported by the Federal Emergency Management Agency for assessing wetland benefits. This value does not overlap with the supporting services value for habitat. The biodiversity services provided by coastal wetlands are valued at \$100 per acre per year or \$300 per hectare per year (in 2018 dollars).

#### **Cultural Services**

Cultural services include recreation and aesthetics.

#### Recreation

The Texas Gulf Coast provides habitat for over 100 species of water birds (Hale et al, 2014). Bird watching tourism was valued in three coastal sites in South Texas by Mathis and Matishoff (2004) to be \$1,600 per acre per year or \$4,000 per hectare per year (updated to 2018 dollars). Adams et al. found that on average birdwatchers spend 2.5 times more than hunters in Texas (1997). Using this ratio, the value of coastal wetlands for hunters was estimated to be \$600 per acre per year or \$1,600 per hectare per year. The total value of bird watching and hunters is estimated to be \$2,200 per acre per year or \$5,600 per hectare per year.

#### **Aesthetics**

Wetlands can be visually rich environments due to their ecological interest and diversity. The aesthetic value for coastal wetlands is based on a hedonic study performed by Doss and Taff (1996) and is the national value supported by the Federal Emergency Management Agency for assessing wetland benefits. The aesthetic value of coastal wetlands is valued at \$1,900 per acre per year or \$4,800 per hectare per year (in 2018 dollars).

## **Application of Monetized Values for Coastal Wetlands**

The values monetized for coastal wetlands apply to healthy coastal wetlands with the exception of storm protection services, which only applies to coastal wetlands near infrastructure at risk for flood damage. The coastal wetland value per acre per year is \$14,900 or \$37,200 per hectare

per year without storm protection services. With storm protection services, the coastal wetland value increases to \$21,600 per acre per year or \$53,800 per hectare per year. **Table 2-2** displays a summary of the monetized values for coastal wetlands and a description of the monetized value. While the average values estimated are good proxies, the full value of wetlands is likely underestimated.

**Table 2-2: Coastal Wetlands Summary** 

Ecosystem Service	Average Annual Value per Acre	Average Annual Value per Hectare	Description
Provisioning	\$4,500	\$11,100	Applies to healthy wetlands
Storm Protection	\$6,700	\$16,600	Applies to coastal wetlands near infrastructure at risk for flood damage
Water Filtration	\$800	\$2,000	Applies to healthy wetlands
Nutrient Control	\$600	\$1,500	Applies to healthy wetlands
Carbon Sequestration	\$4,600	\$11,400	Applies to healthy wetlands
Habitat	\$200	\$500	Applies to healthy wetlands
Recreational	\$2,200	\$5,600	Applies to healthy wetlands
Biodiversity	\$100	\$300	Applies to healthy wetlands
Aesthetics	\$1,900	\$4,800	Applies to healthy wetlands

Note: All values rounded to the nearest hundred.

#### **Coastal Bottomland Forests**

Bottomland forests of the Texas coast provide provisioning, regulating, supporting, and cultural services. Provisioning services include harvesting timber; however, a general value was not quantified for the Texas coast. Regulating services include storm protection and water supply, nutrient control, and carbon sequestration. Supporting functions of the bottomland forests are provided by valuable habitat for migrant birds, waterfowl, and other wildlife. The habitat created by the bottomland forests also provides cultural and recreational services, although these services were not monetized.

## Regulating

Bottomland forest regulating services include water quality improvements and impacts on the water supply from the inundation of floodwaters over the natural landscape, nutrient control, and carbon sequestration.

## **Storm Protection and Water Supply**

Bottomland hardwoods serve a critical role in the watershed by storing floodwater, which reduces the risk and severity of flooding to downstream communities (EPA, 2018). Flood damage protection and impacts on the water supply from bottomland forests were estimated by Moore et al. in Georgia to be \$9,500 per acre per year or \$23,400 per hectare per year for urban and sub-urban bottomland forests and \$5,400 per acre per year or \$13,200 per hectare per year for rural bottomland forests, in 2018 dollars (2011).

#### **Nutrient Control**

Excessive nutrient accumulation from anthropogenic sources can be mitigated through natural denitrification and nutrient uptake processes provided by bottomland forests. The rates of denitrification and retention rates vary depending on elevation of the bottomland forest, age, and the concentration of nutrient pollution. A study conducted in the Mississippi Alluvial Valley reported that low elevation forested wetlands displayed denitrification rates 10 times higher than high elevation forested sites (Jenkins et al, 2009). Jenkins et al found that as a wetland bottomland forest grows the contribution of denitrification to the total removal volume of nitrate from the system increases from only 10 percent in the early years to nearly 50 percent after 90 years because of the change of growth rates of vegetation and soil sedimentation and deposition rates (2009). Systems exposed to higher concentrations of nutrient pollution will exhibit higher denitrification and retention rates than those subjected to lower loads (Hale et al, 2014).

The similarities between the denitrification rates and nutrient retention of a forested riparian zone compared to a bottomland forest suggest that the ecosystem designation as a "riparian forest," a "bottomland forest," or a "forested wetland" will generally refer to very similar habitat types that exhibit similar functionalities for water quality improvement through denitrification and excess nutrient retention (Hale et al, 2014). Considering four studies conducted along the Gulf Coast, on average it is estimated that bottomland forests can remove 36 pounds of nitrogen per acre per year (75.6 percent removal/retention), ranging from 27.6 to 46 pounds of nitrogen per acre per year (Lowrance et al, 1997; Mitsch, 1999; Lowrance, 1984; Jenkins et al, 2009).

Using the average value of \$166 per pound of nitrogen removed from the Ribaudo et al. study (2005), bottomland forests can be valued at \$6,000 per acre per year or \$14,800 per hectare per year for nitrogen removal services.

## **Carbon Sequestration**

The Texas coastal bottomland forests store large masses of carbon in the high volumes of wetland grasses, understory vegetation, large hardwood trees, and organic laden soils and also sequester carbon at high rates through natural vegetation growth, soil formation, and biogeochemical processes within the soils and waters (Hale et al., 2014). Hale et al (2014) estimated that the Texas bottomland forests sequester an average of 1.8 tons of carbon per acre per year based on a review of seven studies of similar forest types in Louisiana and the Mississippi Alluvial Valley (values ranged from 0.9 to 2.4 tons of carbon per acre per year). The average value for carbon per acre per year was converted to 981 pounds of carbon dioxide per acre per year and then monetized using the 2018 value for the social cost of carbon developed by the Federal Interagency Working Group on Social Cost of Carbon. The average annual value of carbon per acre is \$300 or \$800 per hectare.

## **Supporting**

Coastal bottomland forests provide living space for wild plants and animals, both resident and migratory, game and non-game species. The value of the bottomland forest habitat varies depending on the rare species abundance in the area. Rare species abundance refers to the importance of a particular parcel in providing habitat for key species. Low rare species abundance includes areas with zero to five rare, threatened, or endangered species; medium rare species abundance includes areas with six to 11 species; and, high rare species abundance includes areas with more than 11 species.

The average habitat value of Texas bottomland forests with middle or high rare species abundance was estimated by Moore et al. to be \$300 per acre per year or \$700 per hectare per

year, in 2018 dollars (2011). Texas bottomland forests with low rare species abundance were valued at \$30 per acre per year or \$80 per hectare per year, in 2018 dollars.

#### **Cultural Services**

The bottomland forests of the Central Texas Coast are a vital refuge for migratory birds as they complete their journey over the Gulf of Mexico (Faulkner, 2004). The U.S. Fish and Wildlife Service observed 237 species of birds (over 29 million individuals) utilizing the bottomland forests during their annual migration (U.S. Fish and Wildlife Service, 1997). The nature-tourism industry is a powerful economic driver that can capitalize easily on the promotion of prime bird habitat provided by the bottomland forests of the central Texas coast (Hale et al., 2014). The habitat created by bottomland forests provides cultural and recreational services, although these services were not monetized.

## **Application of Monetized Values for Coastal Bottomland Forests**

Although provisioning and cultural services may also apply to the value of coastal bottomland forests, these services were not monetized for the Texas coast. The regulating services pertaining to nutrient control and carbon sequestration would apply to all Texas coastal bottomland forests assessed. The value for water regulation and supply services vary depending on whether the coastal bottomland forests are located in an urban/sub-urban area or rural area. The supporting services for coastal bottomland forests differ depending on the abundance of rare species. While the average values estimated are good proxies, the full value of coastal bottomland forests is likely underestimated.

**Table 2-3** displays a summary of the monetized values for coastal bottomland forests and a description of the monetized value. While the average values estimated are good proxies, the full value of coastal bottomland forests is likely underestimated.

Average Annual Average **Ecosystem Service Annual Value** Value per Description per Acre **Hectare** Applies to bottomland forests in urban \$9.500 \$23,400 Storm Protection and and sub-urban areas Applies to bottomland forests in rural Water Supply \$5,400 \$13,200 areas **Nutrient Control** Applies to healthy bottomland forests \$6,000 \$14,800 Carbon Sequestration \$300 \$800 Applies to healthy bottomland forests Applies to bottomland forests with \$300 \$700 middle or high rare species abundance Habitat Applies to bottomland forests with low \$30 \$80 rare species abundance

**Table 2-3: Coastal Bottomland Forests Summary** 

Note: All values rounded to the nearest hundred or ten.

## **Mangroves**

Mangroves are characterized by trees that have adapted to seawater and changing tides. The most common mangroves along the Texas coast are called black mangroves that require adequate protection from wave action and are sensitive to cold weather. Mangroves provide a wide range of ecological services such as breaking wave energy, control of shoreline erosion,

nutrient cycling, sequestering carbon dioxide, and providing habitat for birds and marine life. Provisioning services can include fuel wood and timber; however, a general value was not quantified for the Texas coast.

#### Regulating

Mangrove regulating services include storm protection, erosion control, and carbon sequestration.

#### **Storm Protection**

Mangroves can be effective in reducing the flooding impacts of storm surges during major storms. Swell waves and wind are rapidly reduced as they pass through mangroves, which lessen wave and wind damage during storms.

Costanza et al. (2014) monetized storm protection, flood control, drought recovery and other aspects of habitat response to environmental variability mainly controlled by the vegetation structure of mangroves. The benefit of storm protection from tidal marshes and mangroves were estimated to be \$2,600 per acre per year or \$6,400 per hectare per year in 2018 dollars based on the meta-analysis conducted by Costanza et al. (2014).. This value would apply to mangroves that are near infrastructure at risk for flood damage from potential hurricanes.

#### **Erosion Control**

Mangroves can support coastline stabilization by preventing erosion from waves and storms. The benefit from erosion control from tidal marshes and mangroves was estimated to be \$1,900 per acre per year or \$4,700 per hectare per year in 2018 dollars (Costanza et al., 2014). This is an average value based on the meta-analysis conducted by Costanza et al. (2014).

## **Carbon Sequestration**

Mangroves account for about 1 percent of carbon sequestration by the world's forests, but among coastal habitats they account for 14 percent of carbon sequestration by the global ocean (Alongi, 2014). Mangroves sequester carbon far more effectively (up to 100 times faster) and more permanently than terrestrial forests. Further, studies have shown that mangrove forests store up to five times more carbon than most other tropical forests around the world (Silori, 2011).

Mangroves can store large amounts of carbon partly from the deep, organic soils within the mangrove and also the entangled root system. The sediments beneath mangroves are characterized by typically low oxygen conditions, slowing down the decay process and rates, resulting in much greater amounts of carbon accumulating in the soil. Mangroves have more carbon in their soil alone than most tropical forests have in all their biomass and soil combined (Silori, 2011).

The carbon sequestration benefits from mangroves are based on a mangrove-specific meta-regression analysis of 44 studies and 149 observations that span 18 countries, conducted by Salem and Mercer (2012). On average, mangroves sequester 5.27 metric tons of carbon/ha/year and can range from 0.02 to 90.5 metric tons of carbon/ha/year (Salem and Mercer, 2012). The average sequestration rate was converted to pounds of carbon dioxide per hectare per year and then monetized using the 2018 value for the social cost of carbon developed by the Federal Interagency Working Group on Social Cost of Carbon. The average carbon sequestration value is \$400 per acre per year or \$1,000 per hectare per year.

#### **Supporting**

Local variations in topography and hydrology result in differentiation of ecological types of mangroves. The combination of different geomorphological settings contributes to the diversity of mangrove ecosystems, and their specific characteristics of structure and function (Duke, 1992; Twilley et al., 1993, 1996).

## **Nutrient Cycling**

The dense roots of mangroves help to bind and build soils. The above-ground roots slow down water flows, encouraging the deposition of sediments and reducing erosion. Mangroves are major conduits for tidal exchange of dissolved and particulate matter between the forest environment and adjacent coastal waters, as well as net exporters of organic matter and nutrients to the ocean, caused by biological and physical processes within the forest ecosystem (Singh et al., 2005).

The value for nutrient cycling and waste treatment services from mangroves is based on the Costanza et al. (2014) meta-analysis. The nutrient cycling services provided by mangroves are valued at \$78,200 per acre per year or \$193,300 per hectare per year (in 2018 dollars).

#### **Food Production**

According to the meta-regression analysis conducted by Salem and Mercer (2012), fisheries that depend on mangroves produce an average of 539 Kg/ha/year of fish and shellfish (ranging from 10 to 2,500 Kg/ha/year). Using the National Marine Fisheries Service Annual Commercial Landing Statistics database, the average value of landings in Texas for all species in 2016 was inflated to 2018 dollars and then multiplied by the production value. The value of food production from mangroves for fish and shellfish is a value of \$1,300 per acre per year or \$3,100 per hectare per year.

#### **Habitat**

Few fish are permanent residents of mangroves but numerous marine species use mangroves as nursery grounds (Robertson and Blaber, 1992). The habitat value from mangroves is based on the Costanza et al. (2014) meta-analysis. The habitat provided by mangroves and tidal marshes is valued at \$8,300 per acre per year or \$20,400 per hectare per year (in 2018 dollars).

## **Biodiversity**

The genetic resources from mangrove ecosystems are rich and include numerous varieties of microbes, fauna and flora living there. Those genes and genetic information are useful for animal and plant breeding as well as biotechnology (Hsieh et al., 2015). Therefore, genetic diversity can contribute to the security of a continuous and reliable supply of ecosystem services from mangrove ecosystems.

The value for biodiversity from mangroves is based on the Costanza et al. (2014) meta-analysis. The biodiversity services provided by mangroves are valued at \$150 per acre per year or \$370 per hectare per year (in 2018 dollars).

#### **Cultural Services**

Cultural services from mangroves may include recreational activities such as kayaking, wildlife watching, eco-tourism, and recreational fishing. The value for recreational services from mangroves is based on the Costanza et al. (2014) meta-analysis. The recreational services

provided by mangroves are valued at \$1,100 per acre per year or \$2,600 per hectare per year (in 2018 dollars).

## **Application of Monetized Values for Mangroves**

The ecosystem service values that were monetized for mangroves were based on metaanalyses. The values monetized for mangroves apply to healthy mangroves with the exception of storm protection services, which only apply to mangroves near infrastructure at risk for flood damage. The mangroves value per acre per year is \$91,400 or \$225,500 per hectare per year without storm protection services. With storm protection services, the mangroves value increases to \$94,000 per acre per year or \$231,900 per hectare per year.

**Table 2-4** displays a summary of the monetized values for mangroves. While the average values estimated are good proxies, the full value of mangroves is likely underestimated.

Average Average Annual **Ecosystem Annual Value** Value per Description Service per Acre Hectare Applies to mangroves near infrastructure Storm Protection \$2.600 \$6.400 at risk for flood damage **Erosion Control** \$1,900 Applies to healthy mangroves \$4,700 **Nutrient Cycling** \$78,200 \$193,300 Applies to healthy mangroves Carbon \$400 \$1,000 Applies to healthy mangroves Sequestration Food Production \$1,300 \$3,100 Applies to healthy mangroves Habitat \$8,300 \$20,400 Applies to healthy mangroves Biodiversity \$200 \$400 Applies to healthy mangroves \$1,100 \$2,600 Applies to healthy mangroves Recreational

**Table 2-4: Mangroves Summary** 

Note: All values rounded to the nearest hundred.

## **Coastal Prairies**

Prairies once covered over 6.5 million acres of Texas and now occupy less than 1 percent of these lands or about 65,000 acres (Baldwin et al., 2007). Coastal prairies can provide provisioning services such as grazing land for ranching and hunting land. Regulating services include nutrient control, carbon sequestration, and erosion control. Supporting services include habitat and biodiversity. Cultural/non-use services can be defined by aesthetics and recreational value.

## **Provisioning**

Provisioning services from coastal prairies include food and water. Prairies are habitat for wild game and fruiting plants. Prairies may be grazed by both wildlife and domestic livestock. The well-draining soils allow rainfall to quickly infiltrate the soil and become groundwater. The de Groot et al. (2012) meta-analysis valued provisioning services from coastal prairies at \$600 per acre per year or \$1,600 per hectare per year (updated to 2018 dollars).

#### Regulating

Coastal prairies regulating services include nutrient control, carbon sequestration, and erosion prevention. Although, coastal prairies can support flood control through rainfall absorption by soil and plants, these benefits were not monetized. Coastal prairies may replace expensive drainage systems and retention ponds.

#### **Nutrient Control**

Coastal prairies are sinks for inorganic nitrogen and help regulate water quality by capturing and controlling the release of nutrients (Hale et al, 2014). Forbes et al (2012) estimated that on average, prairies retain 7.36 pounds per acre per year of nitrogen. Additionally, prairie tallgrass can remove 22 pounds of nitrogen per acre per year on average (Risser et al., 1982; Seastedt, 1988). This is considered to be a conservative estimate. A study conducted in Missouri in 1969 found similar results in terms of nitrogen retention in prairie soils but calculated that prairie grass could filter 33 pounds of nitrogen per acre per year (Risser et al., 1982). Using the average value of \$166 per pound of nitrogen removed from the Ribaudo et al. study (2005), prairies can be valued at \$4,900 per acre per year or \$12,000 per hectare per year for nitrogen removal services.

## **Carbon Sequestration**

Prairies can sequester large amounts of carbon depending on land management practices and vegetation cover. Native prairies grasses have extensive root systems that can spread as far as 15 feet underground and carbon is stored both in the root systems and the soil underground as plants grow and form new soil (Hale et al., 2014).

The average value from four studies conducted either in Texas or in similar habitats in the midwest was estimated to be 1,037 pounds of carbon sequestered per acre per year. The values from the four studies ranged from 712 to 2,386 pounds of carbon per acre per year (Dugas et al., 1998; Potter et al., 1999; Sim and Bradford, 2001; Suyker and Verma, 2001). The average value was converted to 3,800 pounds of carbon dioxide per acre per year and then monetized using the 2018 value for the social cost of carbon developed by the Federal Interagency Working Group on Social Cost of Carbon. The annual value of carbon per acre is \$100 or \$200 per hectare.

## **Erosion Control**

The root systems of coastal prairies prevent soil erosion. If the trees and grasses in a coastal prairie were cut, the soils would become easily eroded by wind and water. Erosion prevention services from coastal prairies were valued utilizing the meta-analysis work of De Groot et al. (2012). The annual value of erosion control services from coastal prairies is \$20 per acre or \$50 per hectare, updated to 2018 dollars.

## **Supporting**

Coastal prairies serve as living seed banks, providing for future agriculture and restoration projects. Prairies and the pollinator species in these habitats safeguard the landscape's genetic heritage. Thousands of species of insects such as butterflies, dragonflies, and imperiled bees rely on prairie plants for their survival. These insects also feed birds and other wildlife.

The highest monetized value from coastal prairies is from the habitat services provided. De Groot et al. (2012) valued habitat services from coastal prairies at \$590 per acre per year or \$1,400 per hectare per year (updated to 2018 dollars) utilizing a meta-analysis.

#### **Cultural Services**

The monetized cultural values from coastal prairies include aesthetics and recreation.

#### Recreation

Coastal prairies increase wildlife habitat and contribute to eco-tourism. Recreational activities may include wildlife watching and photography. Rudolph et al (2014) conducted yearly bird surveys in Texas and found 30 different species of grassland birds. De Groot et al. (2012) valued recreational services from coastal prairies at \$10 per acre per year or \$30 per hectare per year (updated to 2018 dollars) utilizing a meta-analysis.

#### **Aesthetics**

Flowering perennial plants, sweeping grasses, and wildlife make prairies visually appealing. The aesthetic enhancement from coastal prairies can also increase property values within the view shed. De Groot et al. (2012) valued aesthetics from coastal prairies at \$80 per acre per year or \$200 per hectare per year (updated to 2018 dollars) utilizing a meta-analysis.

#### **Application of Monetized Values for Coastal Prairies**

The ecosystem service values that were monetized for coastal prairies were based on metaanalyses or studies conducted in Texas and neighboring states with similar prairie habitats. These values can be combined and applied to assess the value of coastal prairies along the Texas coast. The annual value per acre of coastal prairies is \$6,300 or \$15,500 per hectare. **Table 2-5** displays a summary of the monetized values for coastal prairies. While the average values estimated are good proxies, the full value of coastal prairies is likely underestimated.

Average Annual Value per Average Annual Value per **Ecosystem Service** Acre Hectare Provisioning \$600 \$1.600 \$12,000 **Nutrient Control** \$4,900 Carbon Sequestration \$200 \$100 \$20 \$50 **Erosion Control** Habitat \$600 \$1,400 \$10 \$30 Recreational **Aesthetics** \$80 \$200 \$6.300 Total \$15,500

**Table 2-5: Coastal Prairies Summary** 

Note: All values rounded to the nearest hundred or ten.

## **Beaches and Dunes**

Coastal beaches and dunes provide raw materials (sand) and ornamental resources (e.g., shells, driftwood, coral, and sea glass), however, these resources were not monetized. Besides the recreational and tourism value associated with beaches, coastal beaches and dunes offer protection from coastal storms, control coastal erosion, and provide habitat.

#### Regulating

The regulating services from beaches and dunes include storm protection and erosion control.

#### **Storm Protection and Erosion Control**

Coastal beaches and dunes ability to provide storm protection depends on their size and specifically for dunes, the presence of vegetation and sand supply from the beach (Hesp, 1989; Hacker et al., 2012). The meta-analysis conducted for New Jersey by Liu et al. estimated storm protection from beaches and vegetated dunes to be \$35,600 per acre per year or \$87,900 per hectare per year in 2018 dollars (Liu et al., 2010). This value combines beaches with dunes and is similar to the cost of artificial dunes estimated by Mendoza-Gonzalez et al.

Mendoza-Gonzalez et al. (2012) found that artificial dunes that were built in front of a property to protect against the impact of storm surges and hurricanes and control erosion cost \$6,250 (in 2018 dollars) to cover 37.5 m². Considering this structure would need to be replaced every 20 years, the protection value from dunes was estimated to be \$33,600 per acre per year or \$83,100 per hectare per year.

To be conservative, the Mendoza-Gonzalez et al. values are suggested to value beaches and dunes that provide protection for property in locations where property owners would otherwise build protective devices.

#### **Cultural Services**

Cultural services from coastal beaches and dunes can include both the use and non-use value.

#### Recreation

Parsons et al. conducted a random survey of 884 Texas residents living in a county within 200 miles of the coast in 2001 to understand the recreational day-use value for beaches. Their study included 65 beaches along the Gulf coast of Texas. The per-trip value was estimated to be \$38.75 per-person (updated to 2018 dollars). This value excludes night beach use, non-use values, and values related to other uses of the beach (Parsons et al. 2008). To estimate the daily value of a particular beach, the per-person per-trip value of \$38.75 would be multiplied by the average daily number of visitors.

Mendoza-Gonzalez et al. evaluated recreation along the coast of the Gulf of Mexico using the prices of 4-wheel drive and sand-board rentals and estimated the recreation value of dunes is between \$4,300 to \$6,200 per acre per year or \$10,600 to \$15,400 per hectare per year. If recreational use is expected to be heavy, the maximum value would be more appropriate, whereas if recreational use is expected to be minimal, the lowest estimated value would be reasonable. If recreational use is unknown, the average value of \$5,300 per acre per year or \$13,000 per hectare per year may be used.

For beaches where the estimated number of visitors is unknown, a general recreational value per acre or hectare may be considered. A meta-analysis conducted for New Jersey included studies conducted in North America or Europe and estimated the combined aesthetic and recreational value from beaches to be \$19,400 per acre per year or \$47,900 per hectare per year in 2018 dollars (Liu et al., 2010).

## **Cultural and Spiritual Value**

The cultural and spiritual values associated with beaches can include aesthetic qualities; cultural heritage and identity; spiritual, sacred, and/or religious importance; inspiration for culture, art, and design; and sense of place. The meta-analysis conducted for New Jersey by Liu et al. estimated the combined cultural and spiritual value from beaches to be \$30 per acre per year or \$80 per hectare per year in 2018 dollars (Liu et al., 2010).

#### **Application of Monetized Values for Beaches and Dunes**

The ecosystem service values that were monetized for beaches and dunes were based on meta-analyses or surveys conducted in Texas. These values can be combined and applied to assess the value of beaches and dunes along the Texas coast. **Table 2-6** displays a summary of the monetized values for beaches and dunes. While the average values estimated are good proxies, the full value of beaches and dunes are likely underestimated.

If the estimated annual number of recreational beach users in unknown and the value per acre or per hectare is used, the value of ecosystem services from beaches is estimated to be \$53,000 per acre or \$131,000 per hectare, per year for beaches that protect property. For dunes that protect property and have recreational use, the value of ecosystem services can be \$38,900 per acre or \$96,100 per hectare, per year.

Average Annual Average **Ecosystem Annual Value** Value per Description **Service** per Acre **Hectare** Storm Protection Applies to beaches and dunes that protect and Erosion \$33,600 \$83,100 property Control Applies to beaches (aesthetics and \$19,400 \$47,800 recreational) Applies to dunes and value depends on Recreational \$5,300 \$13.000 estimated recreational usage \$38.75/person/trip/year, use if estimated N/A N/A annual number of users is available Cultural/Spiritual \$30 \$80 Applies to beaches

**Table 2-6: Beaches and Dunes Summary** 

Note: All values rounded to the nearest hundred or ten.

# **Seagrass**

There is an estimated 233,000 acres of seagrass beds along the Texas Coast (Thorhaug et al., 2017). Seagrass beds are one of the most productive habitats and play an important role in the Texas coastal ecosystem. Seagrass beds are important producers of food (or carbon) for many species ranging from bacteria to turtles, which then support higher trophic levels of organisms. Seagrass offers habitat and nursery ground for numerous species, including shrimp, fish, crabs, and their prey. Nearly all of these species rely on seagrass beds as a refuge or habitat for at least part of their life cycle. Seagrasses also provide habitat for migratory waterfowl, sea turtles, and a variety of wading and diving birds. Some of these animals consume seagrass directly. Additionally, seagrass stabilizes the sediment, oxygenates the water column, reduces harmful bacteria, and reduces greenhouse gasses (Texas Parks and Wildlife, 1999).

Texas has five species of seagrass along the coast: shoal grass (*Halodule beaudettei*), star grass (*Halophilla engelmannii*), manatee grass (*Cymodocea filiformis*), turtle grass (*Thalassia testudinum*), and widgeon grass (*Ruppia maritima*). Shoal grass, a subtropical species, is the most abundant seagrass coast wide. Shoal grass and widgeon grass often occur mixed in the higher salinity parts of all Texas bays and estuaries except for Sabine Lake. The tropical species turtle grass and manatee grass occur as far north as Aransas Bay and are most abundant in the Lower Laguna Madre or Corpus Christi Bay area. Due to its overall small size, star grass occurs in sheltered waters, in the understory along with other types of seagrass in mixed beds (Texas Parks and Wildlife, 1999).

#### **Provisioning**

In many parts of the world, seagrass beds are important cultural and economic resources for coastal people, contributing to human welfare through the provision of fishing and bait collection grounds, substrate for seaweed cultivation, medicines, and food. However, it is illegal to uproot seagrass in Texas, therefore, provisioning services were not monetized.

#### Regulating

Seagrass beds sequester carbon and are stabilizing agents in coastal sedimentation and erosion processes.

#### **Erosion Control**

The seagrass roots trap and stabilize sediments, which improves water clarity, water quality, and also provides protection from coastal erosion. The de Groot et al. (2012) meta-analysis valued erosion control services from seagrass beds at \$12,200 per acre per year or \$30,200 per hectare per year (updated to 2018 dollars).

## **Carbon Sequestration**

The Intergovernmental Panel on Climate Change Wetlands Committee recently recognized that seagrasses make a significant contribution to the global stored carbon sink. In Texas, the highest organic carbon stocks are in the Laguna Madre, between the Padre Island National Seashore and the massive King Ranch (Thorhaug et al., 2017). Subtropical/tropical restored seagrass can sequester large amounts of carbon within a short time following restoration, which differs from mangroves that take some years before sequestration occurs in large amounts (DelVecchia et al., 2014). Greiner et al. found that restored seagrass beds are expected to accumulate carbon at a rate that is comparable to measured ranges in natural seagrass beds within 12 years of seeding (2013).

Lavery et al. studied the variability in carbon storage of seagrass habitats in Australia and found not only variability among seagrass species, but also variability due to the habitats in which they occur. The rate of carbon accumulation is highly dependent on the rate of sediment accumulation and water depth. Lavery et al. results indicate a range of carbon dioxide sequestered per hectare per year between 44 and 815 tons. The lower end of the range is comparable to estimates from Hughes (56.4 tons) and Bann and Basak (50 tons) (Hughes, 2015; Bann and Basak, 2013). Thorhaug et al. studied blue carbon dynamics in the Gulf of Mexico and for five sites located in Texas, annual carbon sequestration ranged from 10.2 to 71.5 tons per hectare (Thorhaug et al., 2017).

Based on these studies, a conservative value of 50 tons of carbon dioxide per hectare per year was used along with the 2018 value for the social cost of carbon developed by the Federal Interagency Working Group on Social Cost of Carbon to monetize the carbon sequestering

value of seagrass beds. The conservative annual value of carbon sequestration is \$1,070 per acre or \$2,650 per hectare.

## **Supporting**

Seagrass habitat supports many species of fish, waterfowl and sea turtles and is rich in genetic diversity. Seagrass beds are also part of the nutrient cycling process,

## **Nutrient Cycling**

Seagrass leaves absorb nutrients in runoff from the land, capturing sand, dirt, and silt particles. Seagrass beds also take up nutrients from the soil and release them into the water through their leaves. Seagrass beds located near urban areas or rivers that experience agricultural runoff would have much higher nutrient processing value than those located in areas less subject to such pollution.

A meta-analysis conducted by Costanza et al. (2014) valued the non-market value of nutrient cycling services from seagrass beds to be \$12,700 per hectare per year or \$31,300 per hectare per year (updated to 2018 dollars), which is nearly the same as the value estimated by Brenner et al. (2010) but a bit more conservative.

#### **Habitat**

Seagrasses provide nursery habitats and shelter for small invertebrates, small fish, and juveniles of larger fish species. Some species are permanent residents in seagrass beds, while others only live there for part of their life cycle. The de Groot et al. (2012) meta-analysis valued habitat services from seagrass beds at \$90 per acre per year or \$230 per hectare per year (updated to 2018 dollars).

## **Biodiversity**

More species diverse seagrass ecosystems exhibit enhanced productivity, nutrient cycling, or resistance to disturbance or invasion relative to other habitats with fewer species (Hughes and Stachowicz, 2004). The de Groot et al. (2012) meta-analysis valued biodiversity services from seagrass beds at \$90 per acre per year or \$220 per hectare per year (updated to 2018 dollars).

#### **Cultural Services**

Seagrass habitat attracts recreational activities such as snorkeling, SCUBA diving, fishing, and non-motorized boating. The de Groot et al. (2012) meta-analysis valued recreational services from seagrass beds at \$120 per acre per year or \$310 per hectare per year (updated to 2018 dollars).

## **Application of Monetized Values for Seagrass**

Current economic valuations for seagrass ecosystems are very limited and incomplete, resulting in grossly undervalued seagrass beds (Dewsbury et al., 2016). While the values estimated are good proxies, the full value of seagrass beds is likely underestimated.

The ecosystem service values that were monetized for seagrass were based on meta-analyses. These values can be combined and applied to assess the value of seagrass along the Texas coast. The annual value per acre of seagrass is \$26,300 or \$64,900 per hectare. **Table 2-7** displays a summary of the monetized values for seagrass. While the average values estimated are good proxies, the full value of seagrass beds is likely underestimated.

**Table 2-7: Seagrass Summary** 

Ecosystem Service	Average Annual Value per Acre	Average Annual Value per Hectare
Erosion Control	\$12,200	\$30,200
Nutrient Cycling	\$12,700	\$31,300
Carbon Sequestration	\$1,100	\$2,700
Habitat	\$100	\$200
Biodiversity	\$100	\$200
Recreational	\$100	\$300
Total	\$26,300	\$64,900

Note: All values rounded to the nearest hundred.

# **Summary**

Ecosystem services from seven types of habitats were evaluated, namely: oyster reefs, coastal wetlands, bottomland forests, mangroves, coastal prairies, beaches and dunes, and seagrass.

**Table 2-8** displays the range of average annual values for each habitat type, presented as the annual value per hectare per year. The average annual values vary depending on the applicability of the ecosystem services to the location. These values are average values for the Texas coast and are intended to be conservative estimates of the ecosystem services provided by each habitat type.

**Table 2-8: Ecosystem Services Summary** 

Habitat Type	Average Annual Value per Hectare per Year	
Oyster Reefs	\$114,300 - \$224,400	
Coastal Wetlands	\$37,200 - \$53,800	
Coastal Bottomland Forests	\$28,900 - \$39,700	
Mangroves	\$225,500 - \$231,900	
Coastal Prairies	\$15,500	
Beaches	\$47,900 - \$131,000	
Dunes	\$13,000 - \$96,100	
Seagrass	\$64,900	

Note: All values rounded to the nearest hundred.

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# **Literature Review**

An initial literature review of data relevant to the Texas coast was performed prior to the convening of the TWG to assess the extent of research conducted on ecosystem services, their benefits, and techniques applied to evaluate them. This report was completed in April of 2020 and includes an in-depth discussion on ecosystem services, techniques used to apply value to ecosystem services nationally and regionally, and online tools available for valuing ecosystem services.



# Valuing Ecosystem Services along the Texas Coast: Incorporating Natural Capital into Coastal Resiliency Planning

# April 2020

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# Introduction

The Texas Coastline is known for its natural beauty, recreational opportunities, and the economic benefits derived from coastal industries such as shipping, tourism, and fishing. Approximately 40% of the world's population is settled along the coastlines. An estimated 40% of the U.S. population lives in coastline counties (including the Great Lakes), with numbers continuing to increase (NOAA 2020a). The population of coastline counties in the Gulf of Mexico region increased by 24.5% between 2000-2016, the fastest among coastline regions in the U.S. In Texas, as of 2016, almost 25% of the state population lived in coastal areas; Harris County has accounted for the largest share of the entire Gulf of Mexico region's growth, increasing 35% since 2000 (U.S. Census Bureau 2019; NOAA 2020b). Coastal living has many advantages, but the coastline and coastal communities face a number of unique natural hazards such as storm surge, hurricanes, extreme high tides, sea level rise, shoreline erosion, and harmful algal blooms, as well as social and economic pressures from increased development, increased oil and gas drilling, and overfishing, among others (NOAA 2020b).

In the State of Texas, the coast is both the main trade hub for the rest of the state and the leading energy producer for the nation. As coastal populations increase, so does the need for better ways to increase coastal resilience to natural and human-caused hazards. In the 2019 Texas Coastal Resiliency Master Plan (TCRMP), the Texas General Land Office (GLO) provided a strategic pathway to restore, enhance and protect the Texas coast. The GLO identified eight priority issues of concern that encompass the risks and threats to the viability of its coastal communities, habitats and industries (Table 3-1):

Table 3-1: GLO Priority Issues of Concern: Risks and Threats to Coastal Communities and Resources

- 1. Altered, Degraded, or Lost Habitat
- 2. Gulf Beach Erosion and Dune Degradation
- 3. Bay Shoreline Erosion
- 4. Existing and Future Coastal Storm Surge Damage
- 5. Coastal Flood Damage
- 6. Impacts on Water Quality and Quantity
- 7. Impact on Coastal Resources
- 8. Abandoned or Derelict Vessels, Structures, and Debris

Traditional strategies and approaches to coastal hazard mitigation and resiliency have relied heavily on gray (built) infrastructure, yet gray infrastructure has its shortcomings. Green infrastructure on the other hand, draws on the ecosystem services that nature provides. While green infrastructure supports important co-benefits, it alone cannot substitute for the civil engineering that gray infrastructure provides. Hybrid strategies based on the use of both natural and/or nature-based coastal green infrastructure systems in conjunction with traditional grey infrastructure offer maximum flexibility.

The 2017 TCRMP acknowledged the added value of ecosystem services and the role they could play in infrastructure projects and resiliency planning. AECOM prepared a 2018 memorandum that helped to refine the economic valuations of ecosystem services for the Texas coast, identifying the need for a finer scale tool to improve ecosystem service estimates at a site-specific level using an uncertainty analysis (AECOM 2018). For the 2019 TCRMP, the GLO acknowledged that while the benefits of ecosystem services are



recognized, there is limited ability to directly compare green or hybrid infrastructure benefits and costs to those of gray infrastructure when assessing and selecting projects and identifying potential funding sources. As a result, the opportunity to implement hybrid solutions for projects that are creating a more resilient Texas coastline can fall short.

The GLO recognizes the Texas coast as an integrated network of gray infrastructure and diverse natural environments that should be considered in partnership (potential hybrid infrastructure opportunities) to understand and achieve coastal resiliency. The 2019 CRMP:

- provides an adaptable planning process that accommodates changing conditions and the evolving needs of Texas citizens; and
- serves as a tool for selecting and implementing projects that produce measurable ecological and economic benefits (Texas CRMP 2019).

As part of the adaptive management process and in order to improve the future project selection process, the GLO is interested in gaining a better understanding of the costs and the value of the benefits provided by green and hybrid green-gray infrastructure solutions for coastal resiliency. This interest is part of a greater goal to evolve the project evaluation process by modifying the metrics used to better capture the important values that the nature-based components provide, so that green-gray hybrid infrastructure projects may score higher in evaluation tools, gain greater access to funding sources, and ultimately provide greater project solutions than traditional gray infrastructure alone. As a part of this effort, the GLO is interested in implementing creative green-gray infrastructure hybrid approaches that meet infrastructure resilience needs while drawing on the strengths of green infrastructure, in order to address the eight priority issues and concerns described above (Table 3-1).

The implementation of green infrastructure is becoming more widespread in practice, bolstered by federal efforts such as the Gulf Coast Ecosystem Restoration Council (2013), established in response to the Deepwater Horizon oil spill, that have promoted implementation of green infrastructure for enhanced coastal resiliency at federal, state, and local levels. However, there are still a few challenges and knowledge gaps with implementing green and hybrid infrastructure projects.

This literature review provides an overview of the current state of valuating ecosystem services in Texas and the surrounding Gulf Coast. This review highlights the need to advance natural capital valuations into coastal resiliency planning. The aim is that through the course of this project, GLO and AECOM can work collaboratively with the Technical Working Group (TWG) to advance this field and work toward better tools, data, and best practices for integrating green and hybrid infrastructure into Texas coastal resiliency planning for a stronger and more resilient Texas coastline.

A matrix detailing the studies identified through this literature review, grouped by the GLO planning region in which the study focuses, is provided in Appendix A. At the time of this review, no studies were identified in Region 2.



# **Background**

The following sections provide background on ecosystem services; gray, green, and hybrid infrastructure; and natural capital.

# **Ecosystem Services**

Ecosystem services encompass the direct and indirect contributions, including economic, environmental, and social effects, which ecosystems contribute to the environment and human populations, including tangible goods and benefits (such as the provision of food and materials) (WHCEQ 2013). To conceptualize the full breadth and depth of the type of services that ecosystems provide, both directly and indirectly, the Millennium Ecosystem Assessment (2005) grouped ecosystem services into four categories:

- 1. *Provisioning services* refers to products directly derived from ecosystems, such as food, timber, and fresh water.
- Regulating services are the benefits obtained from regulating ecosystem processes, such as carbon sequestration, storm protection, erosion control, water filtration, and nutrient control.
- 3. *Cultural services* can include recreation, ecotourism, spiritual, and aesthetic value.
- 4. Supporting services form the baseline services necessary to support general ecosystem functioning and include habitat, biodiversity, soil formation, nutrient cycling, and primary production. By maintaining the processes and functions that are imperative for provisioning, regulating, and cultural services, supporting services indirectly contribute to human well-being.

## **Gray Infrastructure**

Traditional strategies and approaches to coastal hazard mitigation and resiliency have relied heavily on gray (built) infrastructure, i.e. human-engineered systems typically built of concrete and steel, such as seawalls, levees, bulkheads, revetments, and groins. Gray infrastructure is generally effective within its design parameters, as there is significant expertise and decades of experience implementing this approach. However, gray infrastructure can be costly to construct and maintain, is not adaptable to changing conditions, and can often have detrimental impacts on surrounding ecosystems and the protective services they provide (USACE 2013; NSTC 2015; Sutton-Grier et al. 2015). Shoreline and offshore hardening approaches can reduce erosion in the project area but accelerate erosion in adjacent locations, reduce the intertidal habitat that supports existing salt marshes and estuarine vegetation, and prevent necessary sediments from reaching beaches and coastal wetlands (USACE 2013; CGIES 2015; USEPA 2019). Gray infrastructure can further lead to habitat fragmentation, declines in biodiversity, increases in invasive species, and reduced habitat migration opportunities inland in response to sea level rise (Bilkovic et al. 2016; Powell et al. 2018)



#### **Green Infrastructure**

Green infrastructure is defined as the use of preserved or restored natural ecosystems or created systems and networks that mimic natural processes (European Commission 2013; USEPA 2019; NOAA 2020c). Intact and properly functioning coastal ecosystems such as salt marshes, mangroves, oyster reefs, seagrass beds, sand beaches, and dunes provide not only goods, such as seafood, but also services, such as wave and wind attenuation, water flow and flood regulation, and soil stabilization and sediment flow. These ecosystem services reduce coastal vulnerability to storms, erosion, flooding, rising sea levels, and similar climate-related hazards (Costanza et al. 1997; Edwards et al. 2013; CGIES, 2015). Green infrastructure also creates opportunities for corridor redundancy – multiple available pathways for wildlife movement. Corridor redundancy improves the connectivity of the natural landscape and improves ecological resilience from extreme events such as flooding, by providing alternate escape routes and refugia for animals seeking safety, as well as pathways for permanent migration of plants and animals (Cushman et al. 2013 and McRae et al. 2012).

In addition to mitigating coastal hazard risks, green infrastructure can provide additional benefits that may not always be immediately obvious or quantified. Co-benefits occur when actions or infrastructure are designed for a specific purpose, but also have secondary or indirect outcomes that contribute to the social, environmental, or economic well-being of the region (Costanza et al. 2008; Smith et al. 2017; Morand et al. 2015). Many co-benefits can have cascading effects. For example, a living shoreline designed to attenuate wave energy and reduce erosion of vulnerable coastal areas may also enhance local habitats and water quality, improving the overall ecosystem. Healthy ecosystems support wildlife abundance and diversity, which thereby increases recreational opportunities (e.g. boating, hunting, fishing, and wildlife viewing) that can contribute to the economic prosperity and well-being of coastal communities. These compounding improvements can also enhance the overall aesthetics of the landscape, resulting in higher adjacent property values.

While green infrastructure approaches to hazard mitigation are generally less costly to implement than traditional gray infrastructure approaches, they can be cost prohibitive when large purchases of valuable land are involved, or difficult or costly restoration work is required. Additionally, green infrastructure approaches often require dedicated monitoring and maintenance funding in order to sustain their functions over time, which can be overlooked in traditional project planning. Furthermore, policy and political barriers may be expensive to overcome (Kousky 2010). Identifying potential co-benefits of green infrastructure projects can facilitate collaborative partnerships among multiple stakeholders and cost-sharing opportunities to achieve simultaneous goals in a region (Morand et al. 2015; Floater et al. 2016).

While green infrastructure provides important co-benefits, it alone cannot substitute for the civil infrastructure that gray infrastructure provides. Hybrid strategies based on the use of both natural and/or nature-based coastal green infrastructure systems in conjunction with traditional gray infrastructure offer maximum flexibility.



## **Hybrid Green-Gray Infrastructure**

Hybrid green-gray infrastructure capitalizes on the best characteristics of built and natural systems to provide solutions that improve both the infrastructure and the surrounding natural landscape, thereby providing for a more comprehensive and robust resilient solution. Hybrid infrastructure can be used in areas where space is limited for implementing natural approaches, allowing for innovation in designing coastal protection systems, and can provide a greater level of confidence than a natural approach alone (Sutton-Grier 2015). For example, "Resilient 37" is a California State Route 37 highway redesign project that is prioritizing early stakeholder involvement and coordination of numerous federal, state, and local agencies to integrate improved functionality of the surrounding ecosystem, enhanced safety features of the roadway, improved vehicle capacity, multimodal transportation, and long-term flood resilience of the region. This hybrid infrastructure approach provides opportunity for project proponents to achieve their shared overarching goals that are not traditionally paired together – roadway redesign, ecological restoration, and flood resilience – for a more resilient overall system (State Route 37 Baylands Group 2017; USEPA, 2018).

Because the use of hybrid approaches is a relatively new practice, there is limited data available on its effectiveness. While hybrid infrastructure may not provide as much habitat or support the same level of species diversity as green infrastructure (Seitz et al. 2006; Sutton-Grier 2015), it may still be preferred over gray infrastructure alone because of factors such as cost and co-benefits. Additionally, hybrid projects allow for the integration of mitigation for project impacts into the project design itself, thereby supporting a more comprehensive and theoretically streamlined environmental planning and permitting approach. Due to their hybrid green-gray nature, hybrid infrastructure projects require early stakeholder communication and integrated scientific and engineering collaboration throughout the design process, which differs from the traditional design approach.

In order to increase the implementation of hybrid/green infrastructure projects into hazard mitigation planning, a way to highlight the value of ecosystem services in green infrastructure is needed. Economic valuation of the ecosystem services provided by green infrastructure is considered to be an effective approach. Economic valuation of natural capital assets and the ecosystem services they provide allows for the costs and benefits of implementing these 'green' approaches to be more fully captured so that they can be more accurately represented in policy, planning and investment decisions. (NRC 2005; De Groot et al. 2012). The next section will explore how ecosystem services are assigned an economic value through the quantification of natural capital.

### **Natural Capital**

In recent decades, with the rapid loss and degradation of the environment, there has been much interest in attempting to assign an economic value to services provided by ecosystems. The costs and benefits of implementing green and hybrid infrastructure projects rely on the preservation, enhancement, restoration, or creation of natural capital (NRC 2005; De Groot et al. 2012; AECOM-UK 2018). Natural capital is the world's stock of natural resources and is an essential component of the ecological systems that are the foundation of life on earth (NCC 2020). Natural capital assets and the ecosystem goods and services that flow from them are crucial to the functioning of earth's life support systems (Costanza et al.



1997). The ecosystem goods and services that flow from natural capital contribute to human welfare, both directly and indirectly, and therefore represent part of the planet's total economic value (Costanza et al. 1997). This natural capital concept is considered an important tool to raise awareness and incentivize the conservation and restoration of the natural world, on which humans rely heavily for continued well-being (De Groot et al. 2012; AECOM-UK 2018).

# **Valuing Ecosystem Services: Framework and Methods**

Ecosystem valuation attempts to capture the range of benefits and costs contained within natural ecosystems through economic methods. Ecosystems and their associated services have economic values for society because people derive utility from their actual or potential use and value services for reasons not connected with use (i.e. non-use values) such as altruistic, bequest, and stewardship motivations (Defra 2007).

Yet assigning an economic value to ecosystem services is challenging. Conventional economic valuation traditionally only considers provisioning services, i.e. the products that can be harvested and sourced from an ecosystem such as timber or food (Costanza et al. 2017). These provisioning services are considered to have market value. Yet, ecosystems provide many other services benefitting humans either directly or indirectly such as regulating, cultural, and supporting services. These services have non-market values, and consequently are often overlooked in valuation efforts (Guerry et al. 2015; Costanza et al. 2017). Valuing these non-market value services is complex and controversial as their value is often not well understood and hence requires many assumptions to be made (Guisado-Pintado et al. 2016; Emerton et al. 2002 from Wood et al. 2010).

Currently, we have a limited understanding of ecosystem functions (Wood et al. 2010) and how ecosystem functions interact with human well-being (Costanza et al. 2017). There is a continued need to develop improved models and tools to explore how regulating and cultural services are connected to human health and well-being metrics (Guerry et al. 2015). As a result of the inherent uncertainties in the valuation process, calculated values are often gross underestimates (Wood et al. 2010).

To gain one step closer towards valuing ecosystems services along the Texas coastline, in the following sections we present the Total Economic Value framework, along with preference-based economic valuation and other methods currently in practice.

### The Total Economic Value Framework

In order to valuate all of the services that flow from a natural capital resource, the Total Economic Value (TEV) framework is increasingly being used to assess both market and non-market values of ecosystem services (Ledoux and Turner 2002 as referenced in Grant et al. 2013). TEV is a concept in Benefit/Cost Analysis (BCA) where humans derive a value from having ecosystem services compared to not having those services. The framework aggregates the values of all services provided by a habitat that are generated now, and in the



future (Pascual et al. 2010). See Figure 3-1 for a simplified conceptual model of the TEV framework.

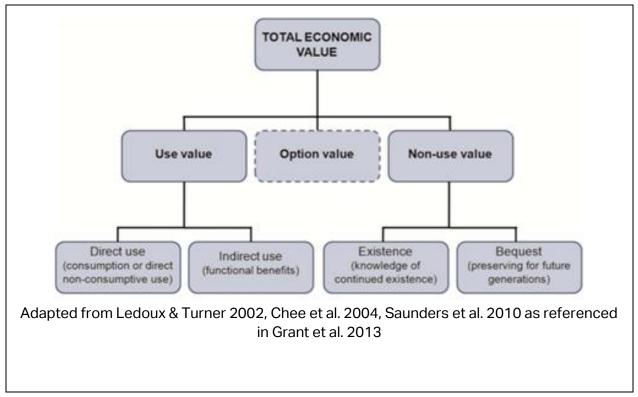


Figure 3-1: Total Economic Value framework for ecosystem services valuation

As described previously, natural capital can provide four general categories of ecosystems services: provisioning, regulatory, supporting, and cultural. These four types of services are further divided into use value, non-use value, and option value, as shown in Figure 3-1.

The TEV framework assumes that humans can hold numerous values for ecosystem services. It was developed to categorize these multiple benefits and to ensure that none of the benefits are excluded from empirical analysis. The TEV framework prevents the double counting of values, especially when multiple valuation methods are used to assign economic values to the various use values, non-use values, and option values that a habitat can provide (NRC 2005).

### **Use Values**

Use values are essentially the values people derive directly from using a good (Defra 2007). Use values measure the preferences for and value of environmental goods/services using various economic methods (e.g., hedonic price, contingent valuation, travel cost, replacement cost, avoided cost, damage cost, production cost). Use value covers direct use and indirect use.

 Direct use value is when individuals make actual or planned use of an ecosystem's services.



 Indirect use value is where individuals benefit from ecosystem services supported by a resource rather than directly using it; these ecosystem services are very important but often not noticed until damaged or lost (Defra 2007).

## **Option Values**

Option values are the values that people place on having the option to use a resource in the future, even if they are currently not a user; future uses may be direct or indirect, such as a national park, and can be thought of as environmental insurance for ecosystem functional roles (Defra 2007).

### **Non-Use Values**

Non-use values, also known as passive use, represents the values people assign to non-consumptive use or intrinsic values and is derived from knowing that the natural environment is maintained (Defra 2007). Non-use values includes bequest value, altruistic value, and existence value.

- Bequest value is when individuals attach value to knowing that an ecosystem resource will be passed on to future generations.
- Altruistic value is where individuals assign value to the availability of a certain ecosystem resource to other individuals in the current generation.
- Existence value is the value attributed to the pure existence of an ecosystem, even though an individual has no planned use for it, such as the willingness to pay for preservation of an endangered species, even though you may never actually see that species (Defra 2007).

# **Methods of Economic Valuation of Ecosystem Services**

Several economic methods for valuating ecosystem services exist. In the following sections we describe three methodologies for valuating ecosystem services, including preference-based valuation, biophysical valuation, and benefit transfer when a primary valuation method is not feasible. These approaches may be used to assess use value, option value, and non-use value.

### **Preference-Based Valuation**

Preference-based approaches are a widely accepted approach to valuating ecosystem services (Pascual et al. 2010). Preference-based valuation relies on observing human behavior and estimating value from individual choices (Pascual et al. 2010). The primary objectives of preference-based valuation are to determine stakeholder preference, how much stakeholders are willing to pay for a service, and to what degree would they consider themselves to be better or worse off due to any changes in the provision of a service (Wood et al. 2010). 'Willingness to Pay' (WTP) and 'Willingness to Accept' (WTA) concepts form the basis of this valuation method. WTP is used when stakeholders do not own the resource providing the ecosystem service or when the ecosystem services provided will be enhanced. Alternatively, WTA is used when stakeholders own the resource or when ecosystem services provided are reduced (Wood et al. 2010).



Conventional preference-based economic valuation includes two main methods for estimating value:

- 1. Revealed Preference methods are based on observed human behavior in a real-world setting. The method analyzes human choices and deduces a value from these observed choices. This method traditionally focuses on products/services that have market value and can be harvested from the environment, such as fish and timber. Recently, it has also been applicable to some non-market value services as well, such as erosion control provided by forests for agricultural production (Costanza et al. 2017). Additional revealed preference methods include replacement costs or hedonic/shadow pricing, which deduces ecosystem service values from closely related parallel markets such as real estate (Fioramonti, 2014 as referenced in Costanza et al. 2017).
- 2. Stated Preference methods rely on analyzing individual responses to carefully designed survey questions. The method includes using contingent valuation and choice experiments. Contingent valuation includes a survey structure using a referendum method and familiarizes respondents to ecosystem improvements with the resulting ecosystem services they will provide (Olander et al. 2015; Costanza et al. 2017). Choice experiments present respondents with combinations of ecosystem services and monetary costs and asks respondents to select the most preferred combinations. Based on these selections, ecosystem service values are estimated (Ryffel et al. 2014; Chaikaew et al., 2017 as referenced in Costanza et al. 2017). There is some controversy surrounding this method as it relies on survey responses and not observed behavior. However, stated preference methods can measure both market and non-market values (Olander et al. 2015).

Both methods require complex statistical methods for estimating value (Costanza et al. 2017). Choice of valuation method should be based on the ecosystem services and types of values that will be essential to the needs of the project. Stated preference is recommended when trying to value ecosystem services with no market value or where human behavior cannot easily be observed (Olander et al. 2015).

### **Benefit Transfer**

Revealed and stated preferences fall under primary valuation methods to estimate value. These two methods both require significant time and resources to gather the primary data. When this is not possible, the *benefit transfer* method is an additional option. Benefit transfer uses the research results from primary valuation studies at one site and transfers the results to other similar sites (Olander et al. 2015). It is also a means to aggregate calculated values to larger spatial scales and contexts (Costanza et al. 2017). See Table 3-2 for different benefit transfer/aggregation methods.

Benefit transfer is generally easier, faster, and less expensive to implement compared to revealed and stated preferences, but it has a greater rate of error (Pascual et al. 2010; Olander et al. 2015). When there are significant differences between two sites (i.e. the site from where the primary value was obtained to the site to which it is transferred), it is advised to correct



values accordingly (Pascual et al. 2010). Transfer errors cannot be avoided. If very precise estimates are required, primary valuation studies should be carried out (Pascual et al. 2010).

Table 3-2: Four levels of ecosystem service value aggregation

Aggregation method*	Assumptions/Approach
Basic Transfer Value	Assumes values are constant over ecosystem types
Expert Modified Value Transfer	Adjusts values for local ecosystem conditions using expert opinion surveys
Statistical Value Transfer	Builds statistical model of spatial and other dependencies
Spatially Explicit Functional Modeling	Builds spatially explicit statistical or dynamic system models incorporating valuation

Source: Costanza et al. 2017

### **Use of Proxies**

For some ecosystem services that are difficult to quantify, such as regulating or supporting services, the use of proxy measures has been useful in estimating an economic value (Costanza et al. 2017). For example, Net Primary Productivity (NPP) – the rate that energy is stored as biomass by primary producers for other consumers in the ecosystem, as shown in Figure 3-2, can provide a good proxy for some ecosystem services and can make assessments easier (Costanza et al. 1998; Costanza et al. 2007; Liquete et al. 2013 as referenced in Guisado-Pintado et al. 2016; Costanza et al. 2017).

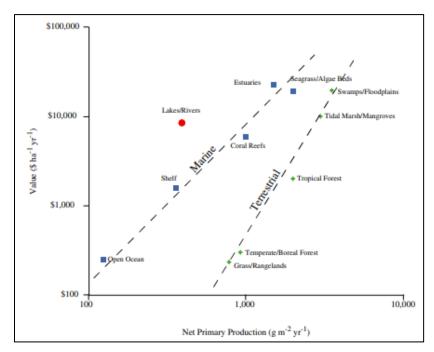


Figure 3-2. Relationship between Net Primary Production and the value of ecosystem services by biome Source: Costanza et al. 1998, as cited in Costanza et al. 2007

<sup>\*</sup>see table 4 in Costanza et al. 2017 for references to journal articles implementing the benefit transfer methods described in this table.



Alternatively, the cost of a substitute of an ecosystem function, such as the cost to protect a shoreline using gray infrastructure compared to an oyster reef, can be directly used as the value of shoreline protection that an oyster reef would provide (Henderson and O'Neil 2003).

## **Biophysical Valuation**

In Biophysical Valuation, a 'cost of production' approach is taken, which considers the sum of the cost of resources that goes into producing a good or service. This considers the cost of labor, energy or material inputs. In valuing ecosystem services, this method calculates the physical costs of maintaining a specified ecological state (Pascual et al. 2010).

This method is more useful for valuing natural capital stocks that have a biophysical form than for valuing indirect services such as storm protection. It is also useful in calculating the depreciation of natural capital (Pascual et al. 2010). Biophysical valuation relies heavily on implicit assumptions and is not a common method for valuing ecosystem services.

# **Summary**

A thoughtfully designed valuation methodology is imperative in providing meaningful and useful results. In designing a valuation exercise the following defining factors should be considered:

- Define the scope of the analysis and consider which ecosystem services will be
  included or excluded, by choice or necessity, in the valuation process. For example,
  the valuation may only need to focus on a specific ecosystem service such as flood
  control or water purification, but not necessarily consider changes in the quality or
  quantity of the habitat.
- Define the geographic extent of the relevant ecosystems for the valuation process.
- Define the relevant stakeholders. Valuation results are often subject to social, cultural and economic contexts. Identifying and including the relevant stakeholders in the valuation analysis will improve the valuation estimate (NRC 2005; Pascual et al. 2010).

It is important to remember that no valuation technique is perfect. For any valuation effort, the requirements of the analysis will be influenced by the resources and data available. Uncertainty will always be a concern (Costanza et al. 2017). In dealing with uncertainty it is important to be clear and transparent, substantiating why certain courses of valuation were taken and potentially providing alternative options detailing how the valuation could have been conducted (NRC 2005).



# **Regional Efforts**

In the following subsections we discuss regional efforts in ecosystem services valuations in Texas and the greater Gulf Coast.

# **Ecosystem Services of the Mid-Texas Coast**

Blackburn et al. 2014, through the Texas Coastal Exchange, compiled a literature review on the various metrics and values of ecosystem services provided by coastal habitats. The review focused on four coastal habitats along the mid-Texas coastline: oyster reefs, coastal marshes, coastal prairies, and bottomland forests.

For each of the four habitat types, the review considered several studies and primarily assessed the different methods that were implemented to understand the magnitude of services provided and, where possible, report on an estimated economic value of that service. The review looked at studies that were conducted regionally within the Gulf of Mexico; however, if no study existed for a specific ecosystem service, then studies conducted elsewhere on similar habitats were considered. For each habitat type, the relevant provisioning, regulating, cultural, and supporting services were considered where data was available.

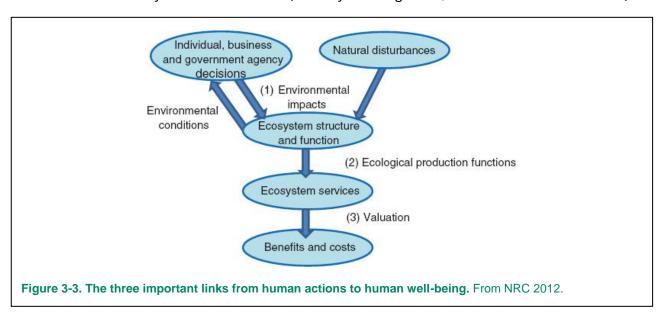
The review recommends that future research should refine upon quantification methods that were assessed, especially for coastal marsh habitats. It underscores the difficulty in identifying exact functionality and economic values due to habitat complexity and the interrelatedness of services provided by habitats such as oyster reefs (Blackburn et al. 2014).

# **Ecosystem Services Approach to Valuating Damages in the Gulf of Mexico**

Historically, damage assessments measure losses in quantifiable ecological terms (e.g. number of acres damaged or number of fish killed) and restoration generally follows a methodology of equivalency, wherein losses are compensated by the replacement of resources of the same type (e.g. acres of habitat restored or fish stocks replaced) (NRC 2012). However, habitat and resource equivalency approaches may not capture the whole value provided by large ecosystems such as the Gulf of Mexico, due to the complex, long-term interactions among ecosystem components (NRC 2012). Furthermore, gaps in baseline data often exist. In an effort to more comprehensively valuate the damage caused in the Gulf of Mexico after the Deepwater Horizon oil spill in April 2010, the National Research Council (NRC) took an ecosystem services approach to valuating the damage caused, based on the four ecosystem service areas of provisioning, regulating, cultural, and supporting services (NRC 2012 and NRC 2014).



An ecosystem services approach fully accounts for an event's impact on all aspects of human well-being (NRC 2014). This approach can be applied to the two phases of remediation: damage assessment and restoration. For damage assessment, the approach looks at the change in the flow of goods and services to people, while for restoration the approach considers a wider range of potential restoration initiatives that will place public resource owners in the same position they were in prior to the destructive event. The approach methodology involves three linkages: (1) the impacts of human actions on environmental conditions that affect the structure or function of ecosystems; (2) how changes in the structure and function of ecosystems lead to changes in the provision of ecosystem services; and (3) how changes in the provision of ecosystem services affect human well-being, and how the value of the changes in services in terms of human well-being can be quantified (Figure 3-3 from NRC 2012). A key benefit is that it does not require that all ecosystem services be measured in monetary terms to be of use (Polasky and Segerson, 2009 as cited in NRC 2014).



# **Ecological Resilience Indicators for 5 Northern Gulf of Mexico Ecosystems**

Goodin et al. 2018 developed a comprehensive set of ecologically informed ecological resilience indicators for salt marsh, mangrove, seagrass, oyster, and coral ecosystems in the northern Gulf of Mexico that can be used to inform sustainable ecosystem restoration and living marine resources management. These indicators address both the ecological integrity and ecosystem services of these ecosystems (Goodin et al. 2018). The authors applied an innovative Ecological Resilience Framework (ERF) that integrated information on ecosystem drivers, ecological integrity, and ecosystem service provision to develop the indicators. This framework was then linked with a comprehensive programmatic and spatial analysis to assess the degree to which the recommended indicators are currently being monitored by existing programs in the northern Gulf of Mexico, identifying gaps in monitoring opportunities for additional data collection.



The authors created Conceptual Ecological Models that identify the critical ecosystem drivers and functions and specify the linkages between them that ultimately effect ecosystem services; used the CEM to identify indicators; and developed quantitative metric ratings (Goodin et al. 2018). As part of this effort, the authors compiled ecosystem range maps, inventoried and completed a spatial analysis of existing monitoring programs, and published the spatial analysis and supporting data for each indicator of each ecosystem via the Coastal Resilience Decision Support Tool (CRDST) (<a href="https://maps.coastalresilience.org/gulfmex/">https://maps.coastalresilience.org/gulfmex/</a>).

### **Texas General Land Office**

The 2017 Texas Coastal Resiliency Master Plan introduced ecosystem services and how they fit into infrastructure projects. The 2018 AECOM Texas Coastal Resiliency Master Plan Ecosystem Services Technical Memorandum (2018 AECOM Ecosystem Services Memo) refined the economic valuations for the Texas coast, providing a baseline of ecosystems services valuation specific to Texas coastal habitats and considering regional and subregional characteristics that affect how ecosystem services are represented at different locations. Ecosystem services related to the presence, creation, and restoration of the following habitat types were considered: oyster reefs, coastal wetlands, bottomland forests, mangroves, coastal prairies, beaches and dunes, and seagrass (AECOM 2018).

The 2018 AECOM Ecosystem Services Memo utilized a benefit transfer approach predominantly drawing on studies specific to the Texas coast or the Gulf Coast that valued similar habitats. Otherwise, national or global studies were used to address data gaps. The 2018 AECOM Ecosystem Services Memo included the limited number of studies specific to the Texas coast or Gulf Coast available at the time. The average values from these studies were used to estimate the value of ecosystem services for the selected Texas coastal habitats. The 2018 AECOM Ecosystem Services Memo considered the relevant provisioning, regulating, cultural, and supporting services specific for each habitat type. In some cases, the values were summed to obtain an average estimated value, while other values are specific to certain conditions. These estimated benefits transferred from other studies were adapted to the Texas coast and adjusted for inflation to 2018 dollars. This information became the basis for the ecosystem service values provided in the 2019 CRMP.

The AECOM Ecosystem Services Memo recognized that the actual value of ecosystem services provided by each of the habitats is very specific to the location and type of habitat. Consequently, valuing these habitats using the benefits transfer approach was challenging when comparing across varying environmental conditions. While an important first step, the values are intended only as high-level estimates (Table 3-3) and do not completely represent the full value of ecosystem services for the entire Texas coast. The Memo calls for the need of a finer scale method to improve ecosystem service estimates at a site-specific level and incorporation of an uncertainty analysis (AECOM 2018).

**Table 3-3: 2019 CRMP Ecosystem Services Summary** 

Habitat Type	Average Annual Value per Acre per Year
Oyster Reefs	\$46,300 - \$90,800
Coastal Wetlands	\$14,900 - \$21,600
Coastal Bottomland Forests	\$11,700 - \$16,100



Habitat Type	Average Annual Value per Acre per Year
Mangroves	\$91,400 - \$94,000
Coastal Prairies	\$6,300
Beaches	\$19,400 - \$53,000
Dunes	\$5,300 - \$38,900
Seagrass	\$26,300

Source: AECOM 2018

# **Online Tools for Valuing Ecosystem Services**

Several online tools and repositories exist to aid evaluating ecosystem services, as shown in Table 3-4. These tools could be useful in assisting the TWG with fine-tuning ecosystem service valuation for Texas coastal habitats. A few key examples are discussed below.

**Table 3-4: Online Tools for Ecosystem Service Valuation** 

Tool Name	Main Function	Method	Requirements of Use	Ownership
InVEST model series	Models can be applied to map and value goods and services from the natural world that contribute to human well-being. Models show how changes in ecosystem structure and function affects the flow and values of ecosystem services throughout a landscape.	This tool is a series of models. The models are spatially explicit, using maps as the input source and produce maps as output products. Results are provided in either biophysical terms (e.g. tons of carbon sequestered) or economic terms (e.g. the net present value of sequestered carbon).	Free to use, models can be accessed at the online links provided. No log-in required.	The Natural Capital Project
GecoServe Ecosystem Services Valuation Database	This database shares information about ecosystem service valuation studies that are relevant to the Gulf Coast region.	Users can select a desired Ecosystem Type and Ecosystem Service. The database outputs a table with all relevant studies that have been completed for the selected preferences. Information includes dollar value of ecosystem service, country/state where study was conducted, and valuation method used.	Free to use. No log-in required.	Texas A&M University and Harte Research Institute



Tool Name	Main Function	Method	Requirements of Use	Ownership
EDGe\$ Economic Decision Guide Software	This online tool is designed to support cost-effective and community-level resilience planning to help communities reduce losses from hazards and allow for more efficient recovery efforts.	This tool is an easy-to-use online platform-independent app that provides standard economic methodology to evaluate investment decisions required to improve communities' ability to adapt, withstand and recover from hazards. This tool allows users to identify and compare the relevant present and future resilience costs and benefits associated with new capital investment versus maintaining a statusquo.	EDGe\$ is free to use and is best run with Google Chrome. Users must create a login to run analyses and view examples.	National Institute of Standards and Technology (NIST) US department of Commerce
ESII tool	The tool can help users identify, inventory and understand ecosystem services at a specific site, inform restoration efforts, and inform benefit/cost analyses when considering green infrastructure.	The tool is comprised of an iPAD app and web interface that allows users to collect spatially explicit ecological data for a specific site in the field. Collected data can be reviewed and edited in the ESII Project Workspace. Ecological models can then be run, and data can be reviewed in a variety of formats.	Free to use. Log-in to ESII Workspace and ESII App is required.	The Nature Conservancy
EVRI database	The database was designed to help find economic values of environmental goods and services or human health impacts, identify studies to apply the value benefit transfer method, and produce defensible value estimates.	EVRI is an online searchable database that stores empirical studies that have assigned a monetary value to environmental resources and human health effects.	Free to use. Log-in/ registering for an account is required.	Environment and Climate Change Canada



FEMA Environme ntal Benefits Calculator	The spreadsheet calculates a Benefit /Cost Ratio (BCR) for a FEMA Hazard Mitigation Project and includes the environmental benefit of purchasing open green space and riparian areas to enhance a hazard mitigation effort.	The calculator is an excel spreadsheet with specific formulas embedded into it.	Free to use. Available online at the FEMA webpage (see hyperlink).	FEMA
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# The Natural Capital Project: InVEST Model Series

The Natural Capital Project (NatCap) is a partnership between Stanford University, the Chinese Academy of Sciences, the University of Minnesota, the Stockholm Resilience Centre, the Nature Conservancy, and the World Wildlife Fund. The partnership is comprised of an inter-disciplinary team of academics, software engineers, and conservation professionals that have developed a systematic approach to weighing nature's benefits to make valuing natural capital easier and more accessible to the public. One of the partnership's primary products is the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) model series. This suite of models is free and open source and can be applied to map and value goods and services from the natural world that contribute to human well-being. The models show how changes in an ecosystem's structure and function affects the flows and values of ecosystem services throughout a landscape. They take into consideration both service supply (e.g. living habitats as buffers for storm waves) and location and activities of people who benefit from ecosystem services (e.g. location of populations and infrastructure potentially affected by coastal storms). The models can help decision makers assess the quantified tradeoffs related to alternative management choices and help identify appropriate areas for investment in natural capital to help restore natural areas and support sustainable human development (NatCap 2020).

The InVEST models are spatially explicit, using maps as the input sources, and produce maps as output products. Results are provided in either biophysical terms (e.g. tons of carbon sequestered) or economic terms (e.g. the net present value of that sequestered carbon). The spatial resolution can be adjusted to meet a project's needs at either a local, regional or global scale. The InVEST tool is modular in that a user does not need to model all the ecosystem services listed but rather users can select those models that are applicable to project needs. InVEST models are a separate application independent of Graphic Information System (GIS) software; however, a mapping software such as QGIS or ArcGIS is needed to view results (NatCap 2020). InVEST models that could potentially be useful to help valuate ecosystem services in coastal regions are listed below (for additional models, see the InVEST Software Platform).

### **Coastal Blue Carbon**

The Coastal Blue Carbon Model analyzes changes of carbon storage in coastal habitats over time and compares it to alternative management scenarios. The model quantifies the values



of carbon storage and sequestration services, as well as valuing avoided emissions and identifying areas of net carbon loss or gain over time.

## **Coastal Vulnerability**

The Coastal Vulnerability Model uses geophysical and natural habitat characteristics of coastal landscapes to determine a coastline's exposure to erosion and flooding in severe weather. This data can be overlaid with coastal population density data to identify areas where humans will face higher risks of damage from storm waves and surge.

## Coastal Protection - Wave Attenuation and Erosion Reduction 1

The Coastal Protection Model quantifies the protective benefits natural habitats provide against erosion and flooding in coastal areas. The model can compute the total water level at the shoreline, the amount of shoreline erosion, and value the amount of avoided damages due to erosion from implementing a given habitat management strategy.

### **Fisheries**

The Fisheries Production Model estimates harvest volume and economic value of single-species fisheries. It is an age- or stage-structured population model that can be adapted to most species and geographies. Using life history characteristics, fishing pressure, habitat dependencies and economic valuation as inputs, the model outputs the volume and economic value of the harvest within the specified area the user has selected.

### Recreation

The Recreation Model maps current and future patterns of recreational use. The model predicts the spread of person-days of recreation based on the location of natural areas and other features that influence where people decide to recreate. The model predicts how future changes in these natural areas will affect visitation rates.

### **GecoServe**

GecoServe is an online Ecosystem Services Valuation Database that is specific to the Gulf of Mexico. It is a project of the Harte Research Institute for Gulf of Mexico Studies at Texas A&M University-Corpus Christi. The database summarizes a variety of studies that have valued ecosystem services for several habitats along the Gulf Coast. The database aims to disseminate and share information about ecosystem service valuation studies relevant to the Gulf Coast and help with identifying data gaps in the ecosystem services literature. The summarized studies have not all been conducted in the Gulf Region but are considered to be relevant.

The 'Valuation Database' tab allows users to select a habitat of interest and corresponding ecosystem services. Once the inputs are selected, the database produces a table that details the habitat type, ecosystem service, dollar value, dollar year, area units, location in which the study was conducted, valuation method used, and references. Users are also able to conduct 'advanced searches' where one can select habitat type and ecosystem service for a specific location/country. The dollar values provided in the table are for reference only and the

<sup>&</sup>lt;sup>1</sup> **NOTE:** Due to this model's dependency on ArcGIS, it was removed from the current InVEST model series and parts of it have now been included in the Coastal Vulnerability model. However, the archived User's Guide can be accessed <a href="here">here</a> and the last InVEST version (InVEST 3.3.3) that includes this model is available <a href="here">here</a>.



website advises to refer to the original study for more detailed information (Santos and Yoskowitz, 2012).

# **Economic Decision Guide Software Online Tool (EDGe\$)**

The EDGe\$ tool is a software product developed by the National Institute of Standards and Technology (NIST), a division of the United States Department of Commerce. This tool is based on the <a href="Community Resilience Economic Decision Guide for Buildings and Infrastructure Systems">Community Resilience Economic Decision Guide for Buildings and Infrastructure Systems</a> (EDG) process produced by NIST. The two resources can be used as standalone tools, but function as part of a more comprehensive planning process that NIST has developed to better manage disaster risk - <a href="Community Resilience Planning Guide for Buildings">Community Resilience Planning Guide for Buildings and Infrastructure Systems</a>.

EDGe\$ is a great resource for economic development and budgeting aimed at community planners, resilience officers and public works officials looking for support in resilience planning and selecting cost-effective projects. The interface is flexible and easy-to-use for a wide range of community and project types. It allows users to run analyses using a seven step process that frames the economic decision tree by identifying and comparing resiliency benefits and costs versus the community doing nothing. The tool allow users to select from various community infrastructure options to analyze and input specific project information based on advanced economic considerations (assignment of bearers of the identified costs/benefits, property rights (externalities), co-benefits and resilience dividends, fatalities averted, and any uncertainty for hazard probability/magnitude, benefits, costs, co-benefits, co-costs). The output yielded includes an easy to comprehend economic indicator report for future planning purposes.

# **Ecosystem Services and Identification and Inventory Tool (ESII)**

The ESII tool is a collaboration between The Nature Conservancy (TNC) and Dow Chemical Company (Dow). This tool, developed by TNC, allows users to generate information on the ecosystem service performance of a targeted landscape. The tool has helped Dow to better understand how changes to their facilities could impact the ecosystem service provision of those landscapes (TNC 2020).

The tool is comprised of an iPad app and web interface that allows users to collect spatially explicit ecological data for a specific site in the field. Once data has been collected it can be reviewed and edited in the ESII Project Workspace, ecological models can then be run, and data can be reviewed in a variety of user-friendly formats. The data provided by the tool can help users to:

- Identify, inventory and understand ecosystem services at a specific site;
- Inform restoration efforts;
- Inform BCAs when considering green infrastructure options, etc.;
- Minimize development related impacts;
- Run 'what if' scenarios; and
- Optimize site layouts/designs for business.



The ESII tool is customizable allowing users to modify the tool for specific operational needs, unique contexts or decision-making processes and is widely applicable from site planning, to impact assessment or BCA studies. Model outputs are available in a number of units of measure, such as percent performance, functional acres/service acres, and traditional engineering units (e.g. gallons per minute). Additionally, using these units of measure and the 'heat mapping' that is produced during an analysis allows users to understand the tradeoffs between proposed activities (e.g. comparing impacts associated with gray vs. green infrastructure). The tool is also designed to track and report sources of uncertainty that result from the analysis.

Ecosystem services currently in ESII that are relevant to Texas CRMP Ecosystem Services project are: carbon uptake, erosion control, flood mitigation, and water quality (for the complete list see the ESII FAQs). It is important to note that this tool has only been used and tested inland, in temperate climates across the U.S. It has been constructed to be broadly applicable across varying geographies; however, as the tool is new, the developers require user feedback in order to better fit the tool to a specific geographic context.

# **Environmental Valuation Reference Inventory (EVRI)**

EVRI is an online, searchable database that stores empirical studies that have assigned an economic value to environmental assets and human health effects. The database was established by the Canadian government's department of Environment and Climate Change in early 1990, together with a number of international collaborators with expertise in environmental evaluation including the U.S. Environmental Protection Agency and the United Kingdom's Department for Environment, Food and Rural Affairs. The online database was launched in 1997 and has since become the largest database storing valuation literature in the world. It currently stores over 4,000 summaries of valuation studies and new studies are continuously being added. The studies are compiled into summaries that detail: study location, the environmental asset being valued, methodology, and estimated monetary value with relevant contextualization. The EVRI database was designed to support its users by helping to:

- · Rapidly find economic values of environmental goods and services or human health impacts;
- · Identify studies to apply the value transfer method and produce defensible estimates of value;
- Collect extensive data for meta-analysis;
- · Explore and compare existing economic valuation methods; and
- Help conduct a detailed literature review of environmental valuation studies.

# FEMA Environmental Benefits Calculator for Hazard Mitigation Assistance Tool: Incorporating Environmental Benefits into the Benefit/Cost Analysis

The environmental benefits calculator serves as an example of how FEMA incorporated benefits derived from ecosystem services into the BCA for FEMA Hazard Mitigation Assistance (HMA) programs. HMA programs include the Pre-Disaster Mitigation,



Flood Mitigation Assistance (FMA), and Hazard Mitigation Grant Program. For project applicants to these grant programs, FEMA has developed a standardized toolkit that calculates a BCR and the social and financial benefits of a potential mitigation activity. Projects are required to be cost effective where their benefits should equal or exceed their costs (BCR greater than 1). Project benefits should cover prevented damages to structures and contents, prevented deaths and injuries, and prevention/reduction of other quantifiable losses.

In 2013, the inclusion of environmental benefits was limited to acquisition-related activities to provide funding for the purchase of riparian areas and open green space. Purchasing and preserving open space was considered an effective method in helping to achieve desired hazard mitigation benefits as these habitats reduce flood risk by maintaining the natural and beneficial functions of the floodplain and removes at-risk structures out of the floodplain.

To valuate the ecosystem services provided by open space and riparian corridors, FEMA collaborated with private, public and academic sectors to develop an Environmental Benefits Analysis Report (EBAR). The report considered the benefits and economic value provided by deed-restricted open space and provided a robust basis to inform economic valuations for the selected habitats in the BCA Toolkit. From these EBAR results, the economic value for the various ecosystem services related to green open space and riparian areas were calculated (Tables 3-5 and 3-6). Consequently, FEMA included an environmental benefits methodology into its BCA Toolkit for acquisition-related mitigation activities (i.e. environmental benefits calculator for HMA).

Table 3-5: The types and values of environmental benefits included in the BCA for acquisition-demolition or acquisition-relocation projects

Environmental Benefit	Green Open Space	Riparian
Aesthetic quality	\$1,623	\$582
Air quality	\$204	\$215
Biological control		\$164
Climate regulation	\$13	\$204
Erosion control	\$65	\$11,447
Flood hazard reduction		\$4,007
Food provisioning		\$609
Habitat		\$835
Pollination	\$290	
Recreation/Tourism	\$5,365	\$15,178
Environmental Benefit	Green Open Space	Riparian
Storm water retention	\$293	
Water filtration		\$4,252
TOTAL ESTIMATED	\$7,853	\$37,493
BENEFITS		

Source: FEMA mitigation policy FP-108-024-01



Note: Dollar year was not available.

Table 3-6: Green Open Space and Riparian Benefits allowed in the BCA Toolkit

Land Use	Total Estimated Benefits	Total Estimated Benefits (projected for 100 years with 7% discount rate)
Green Open Space	\$7,853 per acre per year	\$2.57 per square foot
Riparian	\$37,493 per acre per year	\$12.29 per square foot

Source: FEMA mitigation policy FP-108-024-01

Note: Dollar year was not available.

These monetary values derived for riparian areas and open space do not consider regional differences in property values, nor the difference between rural and urban areas. However, normalizing the environmental benefits through the benefit transfer method in the BCA toolkit was deemed appropriate to account for those differences. As the fundamental purpose of the HMA program is to reduce property damage, environmental benefits cannot be included unless the BCR is 0.75 or greater.

# **Next Steps**

The coastal regions of Texas are some of the most populated, ecologically productive, and economically valuable in the state. Impacts to these areas can disrupt economic, social, and ecological systems in the coastal regions or throughout the state. With increasing pressures and harmful climate-related hazards becoming more frequent, coastal planners and managers need to understand the costs and benefits of all their options in order to move beyond single-objective planning to integrated planning, thereby maximizing ecosystem services benefits for both people and nature. Enough science and tools exist now to support action toward incorporating green and hybrid infrastructure into coastal resiliency and hazard risk reduction planning (Ruckelshaus et al. 2016).

The GLO is in a unique position to develop a standardized protocol for valuing ecosystem services specific to the Texas coast and to develop a methodology to incorporate these dollar values into BCAs. This will greatly improve the decision-making process and assist with identifying potential funding sources.

Moving forward, understanding the physical processes that influence the coastline will be important in helping to determine which areas are most suitable for hybrid infrastructure projects. Even within a distinct geographic region, a single habitat is not physically heterogeneous. There exists spatial, temporal, and non-linear variability, all of which can influence the value of ecosystem services (NSTC 2015; Ruckelshaus et al. 2016). In some cases, the average values of the characteristics of interest may be a reasonable proxy; in others, collecting more spatially explicit data specific to localized project sites will be extremely valuable in calculating more precise dollar values for ecosystem services. In addition, geographic differences in non-ecosystem factors such as the costs of gray



infrastructure development, restoration approaches, and the value of properties to be protected also contribute to spatial heterogeneity in the total value of green and hybrid infrastructure approaches (Ruckleshaus et al. 2016).

The steps the GLO is taking through their adaptive planning process and learning by application places Texas at the forefront for developing best practices for the use of integrated planning to meet varied social, ecological, and economic resilience goals.



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Project reference: TCRMP Project number: 60615820

# **Approach Outline**

This section details the overall objectives of the methodology and provides an outline and description of each step in the process. It also provides a brief summary of the desired outcome as project proponents apply this approach to their coastal resilience projects.



# Hazard Mitigation Funding Opportunity Approach for Coastal Resilience Projects with Ecosystem Services

### **Objective:**

This approach will allow a project proponent to identify nature-based projects that are well suited for hazard mitigation funding. The overall approach will:

- Establish appropriateness of projects for hazard mitigation grant funding opportunities based on local needs for hazard mitigation and the suitability of the project to address the hazard.
- 2. Determine the value of the ecosystem services provided by that project using representative Texas habitat values.
- 3. Identify potential hazard mitigation funding opportunities that are well-suited for the proposed project.

## **Step A - Project Assessment**

In Step A, projects will be systematically assessed and screened based on criteria developed as part of this process to determine if the project would be appropriate for a hazard mitigation funding opportunity under federal or other grant funding programs. During this step, the project proponent will answer a series of questions to screen potential projects for applicability. The tool should highlight those projects more appropriate for hazard mitigation funding over projects that are less appropriate.

### Step B - Risk Index

During Step B, sites that are vulnerable to coastal hazards will be identified. For a project to be considered more appropriate for hazard mitigation funding opportunities, the project site would need to have developed areas that are vulnerable to hazards that would be mitigated under the funding source (e.g., flooding). For hazard mitigation funding, developed areas that are vulnerable are more likely to receive funding due to the increased risk to human life and property, as compared to undeveloped areas. The risk index will help a project proponent select a location for a proposed project that would likely be considered more appropriate for hazard mitigation funding. Risk index maps have been prepared for each hazard assessed:

- Landcover change due to future sea level rise projections
- Inundation due to 1% annual chance storm (100-year storm) FEMA National Flood Hazard maps
- Wave exposure

### **Step C - Value of Ecosystem Services**

Step C will aid a project proponent in describing the benefits of the ecological components of the proposed project. This will be done by characterizing the project by its main ecosystem service functions, such as habitat, biodiversity (species richness), primary productivity, provisioning services, and carbon sequestration. When data is available, quantified benefits may be transferred to the project based on regionally specific monetary valuations of the benefits of ecosystem services (**Appendix B**).



### Step D - Synthesis of Results and Hazard Mitigation Application

After completing the preceding steps, Step D provides a synthesis of the information determined up to this point and how it relates to hazard mitigation funding. Table 8-3 is provided to record and evaluate the results of each step and can be used to organize the relevant hazard mitigation application information. A template of Table 8-3 is provided below, but more detailed information on how to use the table can be found on page 8-4. Step D also includes a list of potential hazard mitigation funding opportunities developed to help a project proponent determine potential opportunities that may be available for funding applications. The list of opportunities includes eligibility requirements for each program and lists key considerations that may play a role in developing a Benefit Cost Analysis, if needed, for the application.

### **Outcomes**

After completing the four steps, the project proponent will have determined which projects have meaningful results and would be appropriate for hazard mitigation funding. The project proponent may at this point select a project and develop an application.



Step A		Step B							
General Project Assessment	Y/N	Risk index score (check box for each)							
Does the project reduce loss of life and property by minimizing natural disaster impacts (e.g., coastal or riverine flooding)?		Hazard	Low	Low-Medi	um	Medium	Medium- High	High	
Does the project enhance, create, or support ecosystems through avoided damages (i.e., is the project a nature-based solution)?		Land Loss Risk Index							
Is the project in need of funding? (partially funded or not funded)		Flood Risk Index							
Is the project in an early planning phase? (conceptual, preliminary design, permitting, final design, shovel ready)		Wave Action Risk Index							
			lf <sup>-</sup>			_			
			S	tep C					
Regulating services score	)			Co	-benefit	s score			
Regulating services	Score	Regulating services	Score	Supporting services	Score	Cultural services	Score	Provisioning services	Score
Storm surge / Flooding protection		Carbon sequestration		Habitat provision		Ecotourism		Fisheries / Grazing / Timber	
Erosion control / Shoreline stabilization				Species richness		Recreation			
Project alignment questions				Listed species					
				Critical habitat					
				Primary productivity					
	General Project Assessment  Does the project reduce loss of life and property by minimizing natural disaster impacts (e.g., coastal or riverine flooding)?  Does the project enhance, create, or support ecosystems through avoided damages (i.e., is the project a nature-based solution)?  Is the project in need of funding?  (partially funded or not funded)  Is the project in an early planning phase?  (conceptual, preliminary design, permitting, final design, shovel ready)  If a "yes" response is achieved for question, proceed to Step  Regulating services  Storm surge / Flooding protection  Erosion control / Shoreline stabilization	General Project Assessment  Does the project reduce loss of life and property by minimizing natural disaster impacts (e.g., coastal or riverine flooding)?  Does the project enhance, create, or support ecosystems through avoided damages (i.e., is the project a nature-based solution)?  Is the project in need of funding?  (partially funded or not funded)  Is the project in an early planning phase?  (conceptual, preliminary design, permitting, final design, shovel ready)  If a "yes" response is achieved for each question, proceed to Step B.  Regulating services  Score  Storm surge / Flooding protection  Erosion control / Shoreline stabilization	Does the project reduce loss of life and property by minimizing natural disaster impacts (e.g., coastal or riverine flooding)?    Does the project enhance, create, or support ecosystems through avoided damages (i.e., is the project a nature-based solution)?    Is the project in need of funding? (partially funded or not funded)   Flood Risk Index	General Project Assessment       Y/N         Does the project reduce loss of life and property by minimizing natural disaster impacts (e.g., coastal or riverine flooding)?       Hazard       Low         Does the project enhance, create, or support ecosystems through avoided damages (i.e., is the project a nature-based solution)?       Land Loss Risk Index         Is the project in need of funding? (partially funded or not funded)       Flood Risk Index         Is the project in an early planning phase? (conceptual, preliminary design, permitting, final design, shovel ready)       Wave Action Risk Index         If a "yes" response is achieved for each question, proceed to Step B.       If a "gent achieved for each guestion, proceed to Step B.         Regulating services       Score Regulating services         Storm surge / Flooding protection       Carbon sequestration         Erosion control / Shoreline stabilization       Stabilization	General Project Assessment  V/N  Does the project reduce loss of life and property by minimizing natural disaster impacts (e.g., coastal or riverine flooding)?  Does the project enhance, create, or support ecosystems through avoided damages (i.e., is the project a nature-based solution)?  Is the project in need of funding? (partially funded or not funded)  Is the project in an early planning phase? (conceptual, preliminary design, permitting, final design, shovel ready)  If a "yes" response is achieved for each question, proceed to Step B.  Step C  Regulating services  Score Regulating services  Storm surge / Flooding protection  Erosion control / Shoreline stabilization  Project alignment questions  Project alignment questions	General Project Assessment  V/N  Risk index (check box in the project reduce loss of life and property by minimizing natural disaster impacts (e.g., coastal or riverine flooding)?  Does the project enhance, create, or support ecosystems through avoided damages (i.e., is the project a nature-based solution)?  Is the project in need of funding? (partially funded or not funded)  Is the project in an early planning phase? (conceptual, preliminary design, permitting, final design, shovel ready)  If a "yes" response is achieved for each question, proceed to Step B.  Regulating services  Score  Regulating services score  Co-benefit  Regulating services  Score sequestration  Erosion control / Shoreline stabilization  Project alignment questions	General Project Assessment  V/N    Risk index score (check box for each)	Conceptual, preliminary design, permitting, final design, shovel ready)   If a "yes" response is achieved for each question, proceed to Step B.   Storm surge / Flooding protection   Store stabilization   Species richness   Store stabilization   Species richness   Store stabilization   Species richness   Species richness   Store stabilization   Species richness   Species richness   Species richness   Store stabilization   Species richness   Speci	Ceneral Project Assessment   Y/N

# **Step A - Project Assessment**

In Step A, projects will be systematically assessed and screened based on criteria developed as part of this process to determine if the project would be appropriate for a hazard mitigation funding opportunity under federal or other grant funding programs. During this step, the project proponent will answer a series of questions to screen potential projects for applicability. The tool should highlight those projects more appropriate for hazard mitigation funding over projects that are less appropriate.



## **Assessing Projects for Hazard Mitigation Funding Approach**

The purpose of this first step will be to determine if a proposed project is likely to be appropriate for hazard mitigation funding under a federal or other grant funding program. Projects can be determined to be potentially appropriate for hazard mitigation funding considering ecosystem service benefits by answering several simple questions.

Consider the questions below to determine a project's appropriateness for hazard mitigation funding. If the project is given a 'Yes' for all these questions, it may be considered appropriate for hazard mitigation funding. If the project is given a 'No' for at least one of the questions, it is likely NOT appropriate for a hazard mitigation funding opportunity at this time.

•	Does the project reduce loss of life and property by minimizing natural disaster impacts
	(e.g., coastal or riverine flooding)?
	⇒Yes □
	⇒No □
•	Does the project enhance, create, or support ecosystems through avoided damages (i.e., is the project a nature-based solution)?
	⇒Yes □
	⇒No □
•	Is the project in need of funding?
	⇒Yes, the project is: □Partially Funded, or □Not Funded
	$\Rightarrow$ No, the project is fully funded $\square$
•	Is the project in an early planning phase?
	<ul> <li>⇒Yes, the project is in:</li> <li>□No funding/Conceptual phase,</li> <li>□Preliminary Engineering and Design/Environmental phase,</li> <li>□Advanced Engineering and Design/Environmental Planning &amp; Permitting phase, or</li> <li>□ Ongoing-Permitting complete/shovel ready phase</li> </ul>
	$\Rightarrow$ No, the project is currently under construction <sup>1</sup> $\square$
•	Projects identified as potentially appropriate (i.e., answered 'Yes' to all the above questions) may proceed to Step B.

<sup>&</sup>lt;sup>1</sup> In some cases, a project that is under construction may be applicable to receive hazard mitigation grant funding if additional funds are needed to construct the project

# Step B – Risk Index

During Step B, sites that are vulnerable to coastal hazards will be identified. For a project to be considered more appropriate for hazard mitigation funding opportunities, the project site would need to have developed areas that are vulnerable to hazards that would be mitigated under the funding source (e.g., flooding). For hazard mitigation funding, developed areas that are vulnerable are more likely to receive funding due to the increased risk to human life and property, as compared to undeveloped areas. The risk index will help a project proponent select a location for a proposed project that would likely be considered more appropriate for hazard mitigation funding. Risk index maps have been prepared for each hazard assessed:

- Landcover change due to future sea level rise projections
- Inundation due to 1% annual chance storm (100-year storm) FEMA National Flood Hazard maps
- Wave exposure



## **Risk Index for Hazard Mitigation in Coastal Texas**

## **Background:**

The Texas Coastal Resiliency Master Plan (TCRMP) provides a list of projects and strategies to be implemented along the Texas coast that will enhance protections for coastal infrastructure, communities, and natural resources from impending natural catastrophes, like tropical storms and hurricanes. As part of the TCRMP planning effort, the GLO is working to identify locations on the Texas coast that are most vulnerable to these natural disasters, with the goal that preand post-disaster hazard mitigation funding might be secured more readily for coastal resiliency projects that mitigate the hazard(s). In particular, the GLO is interested in improving hazard mitigation funding for coastal resiliency projects that incorporate natural and nature-based features (NNBF).

#### **Purpose:**

To justify hazard mitigation funding for projects with NNBF, it is important to identify the vulnerability of project sites and potential project locations along the Texas coast and understand the factors that can reduce the overall risk to hazards at those sites. By identifying which areas on the coast are most at risk for damage and loss of human life or property due to coastal hazards, potential project locations can be identified that will likely provide hazard mitigation benefits. The risk assessment will assist the GLO with identifying locations where hazard mitigation funding is more likely to be available, because of the ability to reduce damages to coastal communities and areas of development.

#### **Objective:**

To achieve the overarching goal of funding hazard mitigation projects in Texas that include NNBF as a component of coastal resiliency, this document will describe a Risk Index, where Risk = Hazard x Vulnerability x Consequence, that can be used to establish the relative vulnerability a location of interest has to future natural disasters (i.e., storms and sea level rise). In the risk formula presented for this approach (Risk = Hazard x Vulnerability x Consequence), hazard is defined as the threat facing the site, vulnerability is defined as the exposure of the site to the threat, and the consequence is defined as the assets potentially exposed to the threat. Once established, the Risk Index can be used to determine the locations on the Texas coast that would be expected to be most be likely to receive hazard mitigation grant funding toward a resiliency project that reduces the effects of the hazard.

The Risk Index will be a standard approach to systematically value areas of the Texas coast that might be most applicable for hazard mitigation funding by virtue of the development in the location and the exposure of the area to hazards. The index will establish the vulnerability of coastal sites to:

- Landcover change—the potential for a site to convert from its present habitat type to a
  different habitat type under future relative sea level rise by the year 2100
- Flooding—change in water surface elevation at a particular site for the 1% annual chance exceedance probability storm event
- **Wave action zones**—relative severity of wave impacts (height of waves expected) at the site under existing site conditions



Once completed, the Risk Index can be used to estimate hazard reduction benefits for proposed project types at a project site. Examples of the benefits from NNBF projects may include:

- Reducing landcover change
- Wave attenuation
- Coastal flood control

- Sediment transport
- Inland/riverine flood control
- Shoreline stabilization

## Step 2 - Risk Index:

The Risk Index includes determinations of vulnerability to three hazards driven by coastal storms and sea level rise: landcover change, flooding during 1% storm event, and wave exposure. This section will describe the different hazard components of the risk index.

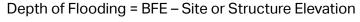
## 1. Landcover Change

The TCRMP includes Sea Level Affecting Marshes Models (SLAMM) for the present-day landscape and the year 2100 landscape with and without relative sea level rise to determine any change in Cowardin landcover classifications. The primary inputs for these models are wetland coverage from the National Wetlands Inventory and landcover data from the US Geological Survey. For each landcover type, an expected change by 2100 can be computed by loss/gain of acreage. The landcover datasets developed for the 2019 TCRMP may be accessed <a href="here">here</a> and used to identify predicted landcover changes due to relative sea level rise at site-specific locations; the Region 1 data link is provided <a href="here">here</a> as an example.

Using the model outputs, the acreage change for habitats of interest at the project site can be isolated and computed to determine the loss/gain of habitat predicted for the project site or location of interest.

#### 2. Flooding

The Federal Emergency Management Agency (FEMA) National Flood Hazard Layer <u>online</u> <u>web viewer</u> may be used to determine the base flood elevation (BFE) of each project site or location of interest. The BFE for a particular location may be compared with the base level elevation of the site or structures at the site to estimate the depth, and therefore severity, of flooding during a 1% storm event.



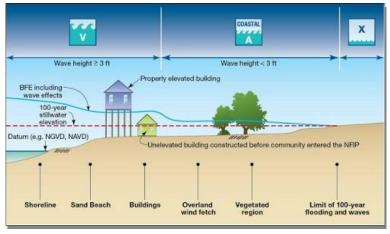


Figure 6-1. FEMA Coastal Flood Zones, Wave Heights, and BFEs



#### 3. Wave Action Zones

During coastal storm events, wave action can pose an additional threat to human life and property versus flooding and wind damage alone. By delineating zones of potential high, medium, and low wave impacts, the GLO can pinpoint areas where coastal resiliency projects would most effectively reduce the likelihood or severity of wave action. Knowing the locations potentially vulnerable to impact by medium and high wave energy can highlight the need for restoration projects in a hazard mitigation application. Projects with NNBF that can be shown to attenuate waves will see a higher benefit to justify their funding and implementation. It is more achievable in many cases for a coastal project to reduce wave effects rather than stillwater levels associated with storm surge.

Through a separate analysis, wave action zones were defined using publicly accessible FEMA Flood Information Study data. The FEMA Special Flood Hazard Areas (SFHAs), which detail the location of flood zones impacted by varying levels of flood events, were combined with the Limit of Moderate Wave Action (LiMWA) data to divide the flood layers into wave action zones based on potential wave height. The LiMWA line identifies areas where waves reach heights of 1.5 feet or greater. A wave impact index to predict the impact of waves on bay shorelines, produced by HRI based on USGS wave exposure methodology, was then used to verify and validate the results of the combined SFHA and LiMWA data and to fill in any gaps that may be present in the FEMA layers. Preliminary results of this analysis are shown below, where the "High" wave action zone is in areas with an SFHA designation of "VE," indicating wave heights greater than 3 feet, the "Medium" wave action zone is in areas with an SFHA designation of "AE" seaward of the LiMWA, indicating wave heights greater than 1.5 feet but less than 3 feet, and the "Low" wave action zone is landward of the LiMWA and in areas with SFHA of designation "AE," indicating wave heights less than 1.5 feet. Ideally, these results would be used in conjunction with the BFE data produced by FEMA to determine if a proposed project would be expected to reduce the wave action zone designation and subsequent BFE.

Each project site or location of interest will be classified as having low, medium, or high wave action zones using maps developed by the GLO Planning Team.

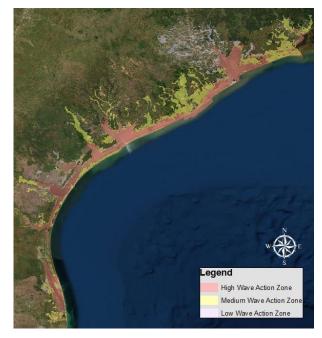




Figure 6-2. High, Medium, and Low Wave Action Zones



## Risk Index Scoring Methodology

## Landcover Change

$$Risk \ Score = \frac{\sum \ (SLAMM \ Score \times SLAMM \ Score \ Area)}{Adjusted \ Quarter \ Quad \ Area}$$

#### Where:

- The SLAMM Score is from the model output feature class (DOQ4\_Coastal\_LandLoss), SLAMMow attribute field. The higher the raw score, the greater the expected land cover change.
- This SLAMM Score Area varies slightly between approximately 640 to 670 acres. The SLAMM output is by 1/64 of a USGS quadrangle or 1/16 of the quarter quad used for generation of the Risk Index maps.
- The Adjusted Quarter Quad Area is the area of the quarter quad minus the area of open water in each quarter quad.

The SLAMM model output was already attributed with a quarter quad field, so the feature class attribute table was exported into excel for calculation. With up to sixteen (16) scores per quarter quad and slightly varying areas, a weighted average of the land score was divided by the adjusted quarter quad area. Open water area was removed from the quarter quad area in the calculation so as not to skew the resulting risk scores.

## **Flooding**

 $Risk\ Score = Percent\ of\ Quarter\ Quad\ in\ Floodplain* Average\ Flooding\ Depth$ 

#### Where:

- The Percent of Quarter Quad in Floodplain was based on FEMA 100-year, 24-hour Effective and Preliminary floodplain extents
- Average Flooding Depth is the average depth value of flooding for each quarter quad

The risk score for assessing flood risk was made up of two components as the type and quality of data available varies based on location. The floodplain extents are a union of the Preliminary and Effective Floodplains. The floodplain union was then intersected with the quarter quad shapefile to calculate the area and percentage of each quarter quad in the 100-year floodplain. The average flooding depth was calculated by creating a water surface elevation raster based on hydraulic model cross section data, where available, and static base flood elevation (BFE) data. The GLO Coastal Lidar was then subtracted from the water surface elevation raster to generate a flood depth raster for each county. The average flooding depth used in each quarter quad was calculated in ArcGIS with zonal statistics. Three (3) counties did not have water surface elevation data available for use: Aransas, Kenedy, and Wilacy Counties. For these and other areas of the 100-year floodplain where water surface elevation data was not available, the average flooding depth of all quarter quads (5.07 feet) was used as an assumed depth value.

#### Wave Action

$$Risk \ Score = \frac{\sum \ (Wave \ Action \ Zone \ Score * Wave \ Action \ Zone \ Area)}{Adjusted \ Quarter \ Quad \ Area}$$



#### Where:

- The three (3) Wave Action Zones were defined from the FEMA Special Flood Hazard Areas (SFHAs) and the Limit of Moderate Wave Action (LiMWA) data
  - Low landward of the LiMWA line and in areas with SHFA designation "AE"; wave heights of less than 1.5 feet.
  - Medium seaward of the LiMWA line and in areas with SHFA designation "AE"; wave heights between 1.5 and 3 feet
  - o High areas with SFHA designation "VE"; wave heights greater than 3 feet
- The Wave Action Zones were then given a Wave Action Score
  - o Low 1
  - o Medium 2
  - High 3
- The Wave Action Zone Area is the area within each quarter quad covered by each of the three Wave Action Zones.
- The Adjusted Quarter Quad Area is the area of the guarter guad minus the area of open water in each quarter quad.

The wave action zone shapefiles were adjusted by removing the open water area to avoid skewing the scores as these risk index maps focus on potential projects on land. The adjusted wave action zone shapefiles were then intersected with the quarter quads and areas of each zone within the quarter quads were calculated. A weighted average of the assigned score and calculated area was taken to generate the risk score for each quarter quad.

#### **Adjustment for Imperviousness**

To take urban development into account when assessing risk, the scores were multiplied by the percent impervious of each quad. The impervious cover data was downloaded from the National Land Cover Database 2016 Developed Imperviousness Descriptor raster file. The raster was converted into polygons in ArcGIS and grouped based on roadway vs nonroadway impervious cover. The resulting impervious cover shapefile was intersected with the guarter guads and areas/percentages of roadway, non-roadway, and total imperviousness were calculated. The risk scores were then adjusted to generate the final risk index maps.

## **Map Visualization**

The risk scores were broken down into six (6) brackets for creating the risk index maps.

## Landcover Change

No Expected Risk / No Available Data	Risk Score 0
Low Risk	0.00 < Risk Score < 1.00
Low – Medium Risk	1.00 < Risk Score < 3.00
Medium Risk	3.00 < Risk Score < 5.00
Medium – High Risk	5.00 < Risk Score < 15.00



High – Risk	Risk Score > 15.00

Flooding

No Expected Risk / No Available Data Risk Score 0

Low Risk 0 < Risk Score < 0.25

Low – Medium Risk 0.25 < Risk Score < 0.50

Medium Risk 0.50 < Risk Score < 1.00

Medium – High Risk 1.00 < Risk Score < 2.00

High – Risk Score > 2.00

Wave Action

No Expected Risk / No Available Data Risk Score 0

Low Risk 0 < Risk Score < 0.03

Low – Medium Risk 0.03 < Risk Score < 0.06

Medium Risk 0.06 < Risk Score < 0.12

Medium – High Risk 0.12 < Risk Score < 0.25

High – Risk Score > 0.25

## **Risk Index Maps**

The hazards resulting from each of the above datasets were compared spatially using GIS software, and the hazards were overlain with present-day development (i.e. impervious surface cover) to indicate the relative exposure of developed areas along the coast to the hazards. The resulting data layers were used to develop risk indices for each of the three primary hazard categories, displayed as a series of quadrant maps, indicating high to low levels of overall risk. The attached maps (Figures 6-4 to 6-15) will help the project proponent determine the level of risk of each hazard type associated with the proposed project area. A description of each map set and how to determine the level of risk is provided below. **Areas of high overall risk for each of the hazards are more likely to be suitable for coastal resiliency projects that would be appropriate for hazard mitigation funding.** 

After completing Step B, the user should be able to determine areas that are suitable for hazard mitigation projects on the Texas coast. Proceeding to Step C, the user should be able to determine which projects in these locations are best suited to provide ecosystem service benefits from the NNBF incorporated into the design. Step D synthesizes the results of Steps A through C and details how each step is applicable to hazard mitigation funding opportunities. Table 8-3 should be used by project proponents to record and evaluate the results from each step.

#### **How to Use the Map Sets**

Each map set contains a series of four maps with information relating to one of the coastal hazards detailed above. The maps are divided by the four TCRMP Planning Regions (Figure 6-3). The first map in each set covers Region 1, the second map in each set covers Region 2, the third map in each set covers Region 3, and the fourth map in each set covers Region 4.

The first set of maps (Figures 6-4 through 6-7) provide information on the risk of land loss to the Texas coast. The quadrants in red are associated with high risk of losing land, the areas in yellow are associated with a medium risk of land loss, and the areas in dark green are associated with low risk of land loss. Areas with no color either do not anticipate any land loss or no hazard data was available, indicating that projects in those areas may not be appropriate for hazard mitigation funding for this vulnerability at this time.

The next set of maps (Figures 6-8 through 6-11) detail the flood risk to areas along the Texas coast. The quadrants in red indicate areas with



Figure 6-3. TCRMP Planning Regions

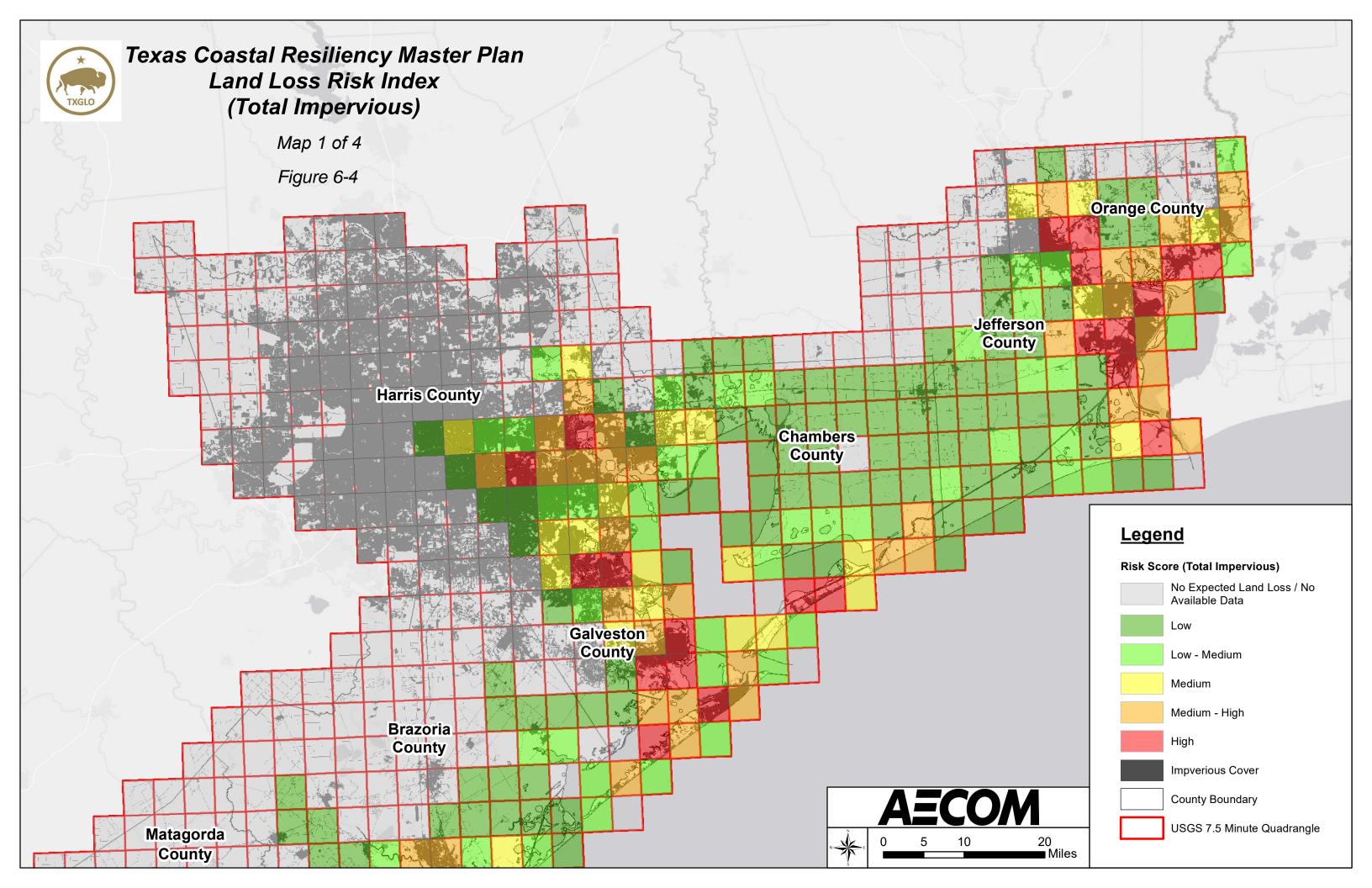
a high risk of flooding during a 100-year storm event (i.e. FEMA defined 1% storm event). Quadrants in yellow indicate a medium risk to flooding during a 100-year storm event and those in dark green indicate a low risk to flooding during a 100-year storm event. Areas with no color either do not anticipate any risk to flooding or no hazard data was available, indicating that projects in those areas may not be appropriate for hazard mitigation funding for this vulnerability at this time.

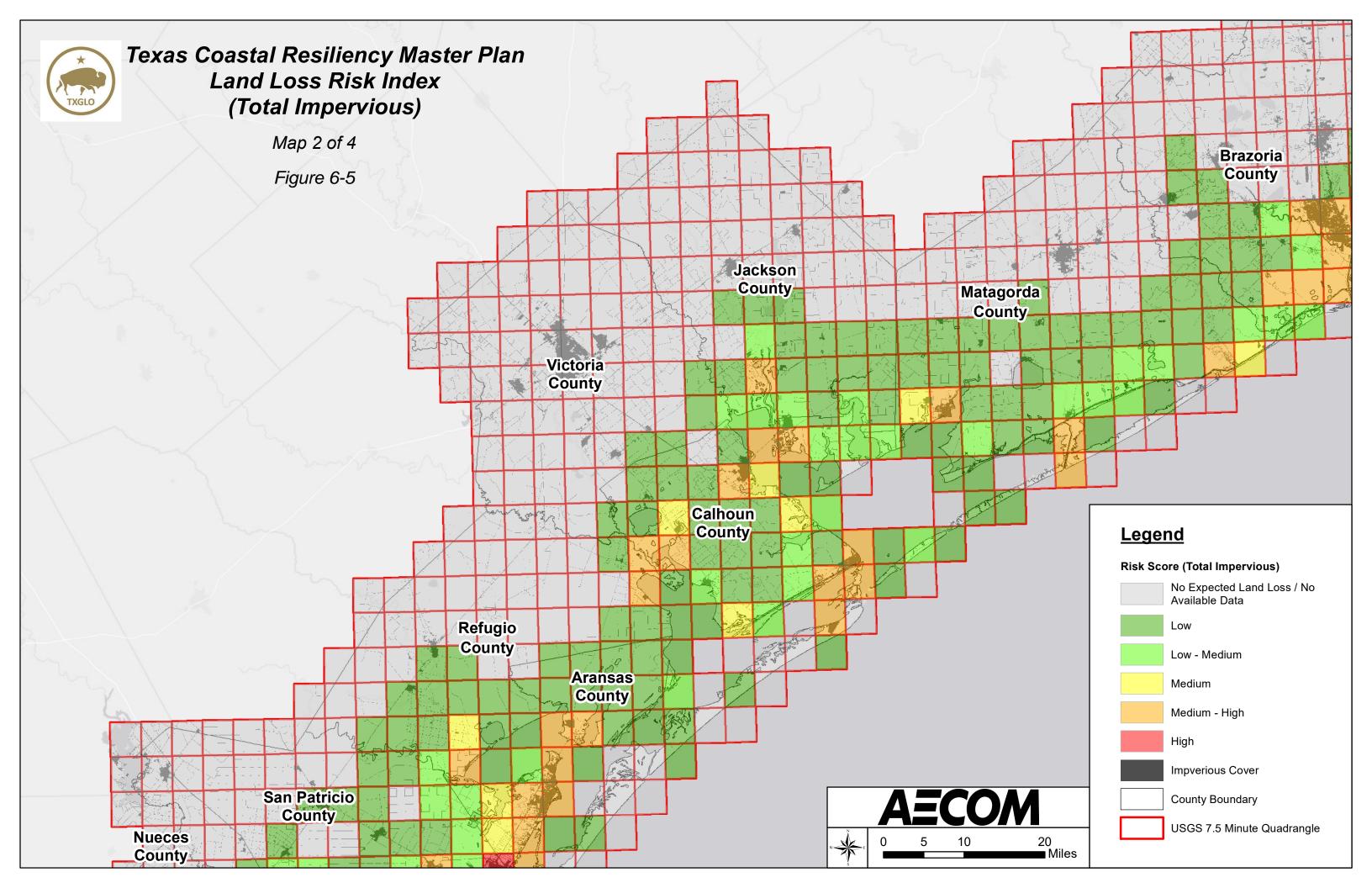
The final set of maps (Figures 6-12 through 6-15) show the risk associated with wave action in areas along the Texas coast. Quadrants in red indicate high risk associated with wave action, areas in yellow indicate medium risk associated with wave action, and areas in dark green indicate low risk associated with wave action. Areas with no risk level indicated do not have hazard data available or are not expected to be at risk to wave action. Projects in these areas may not be currently appropriate for hazard mitigation funding.

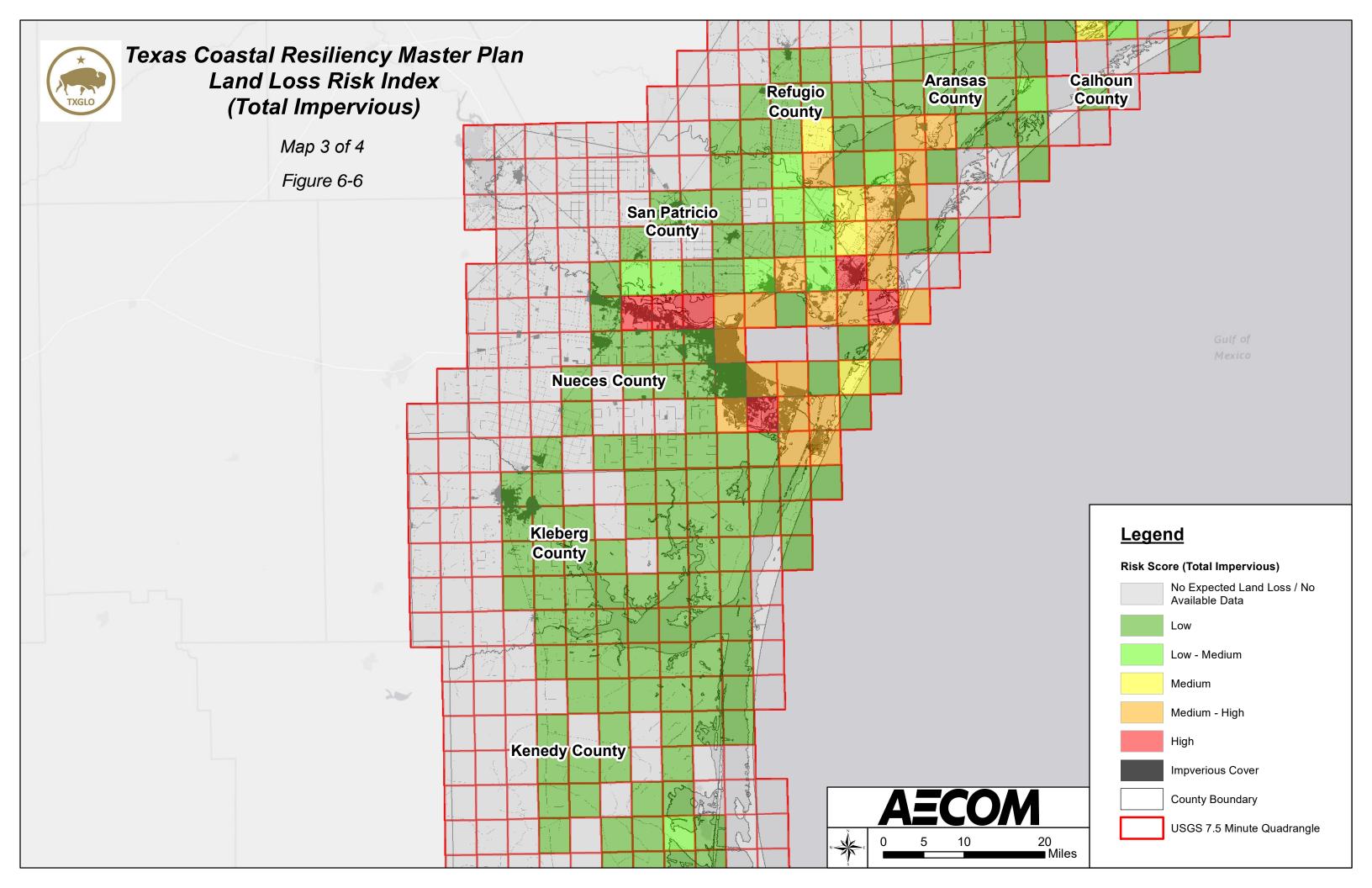
The background data used to develop the Risk Index Maps is included in **Appendix C**.

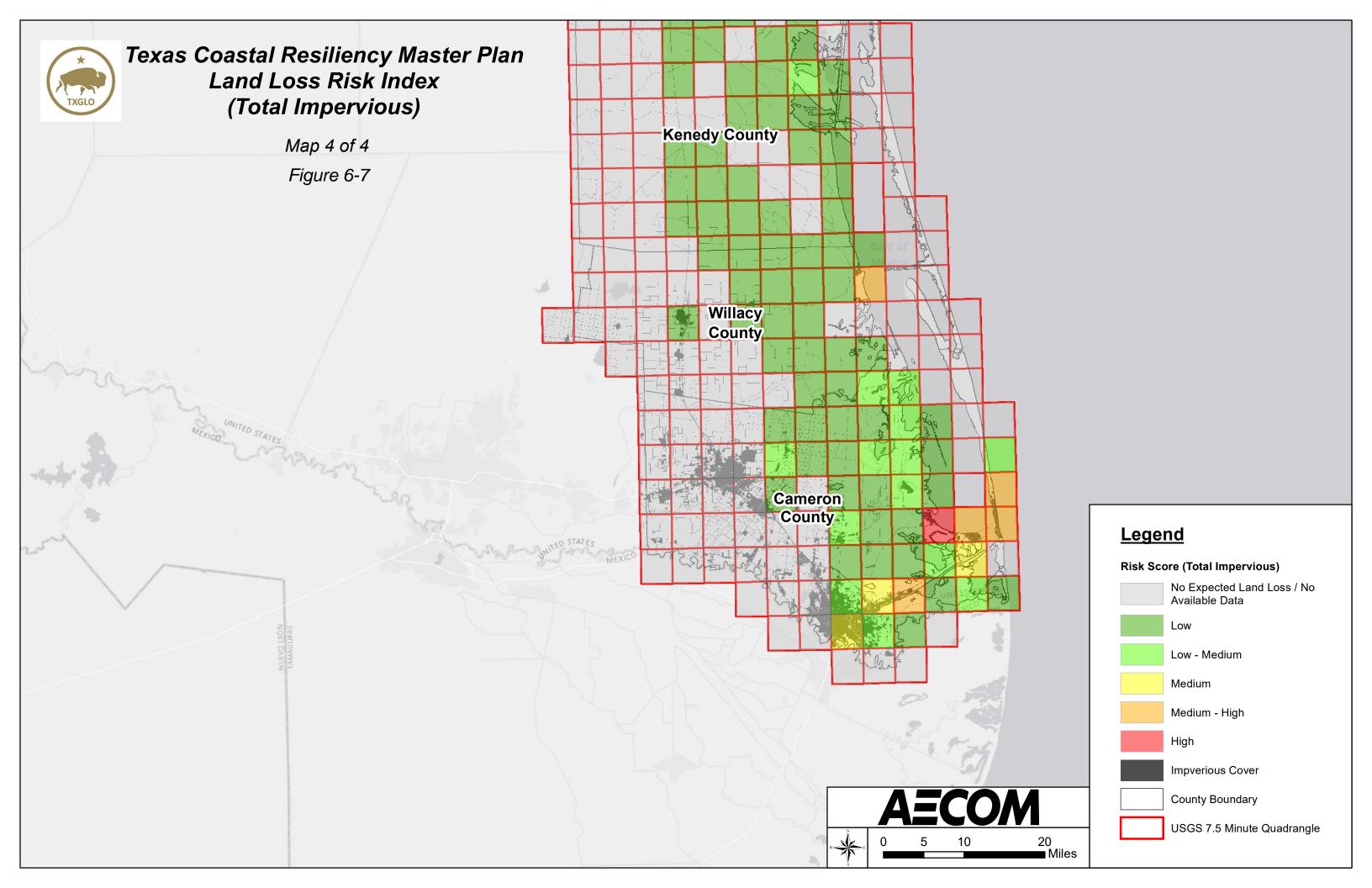
## **Additional Resources**

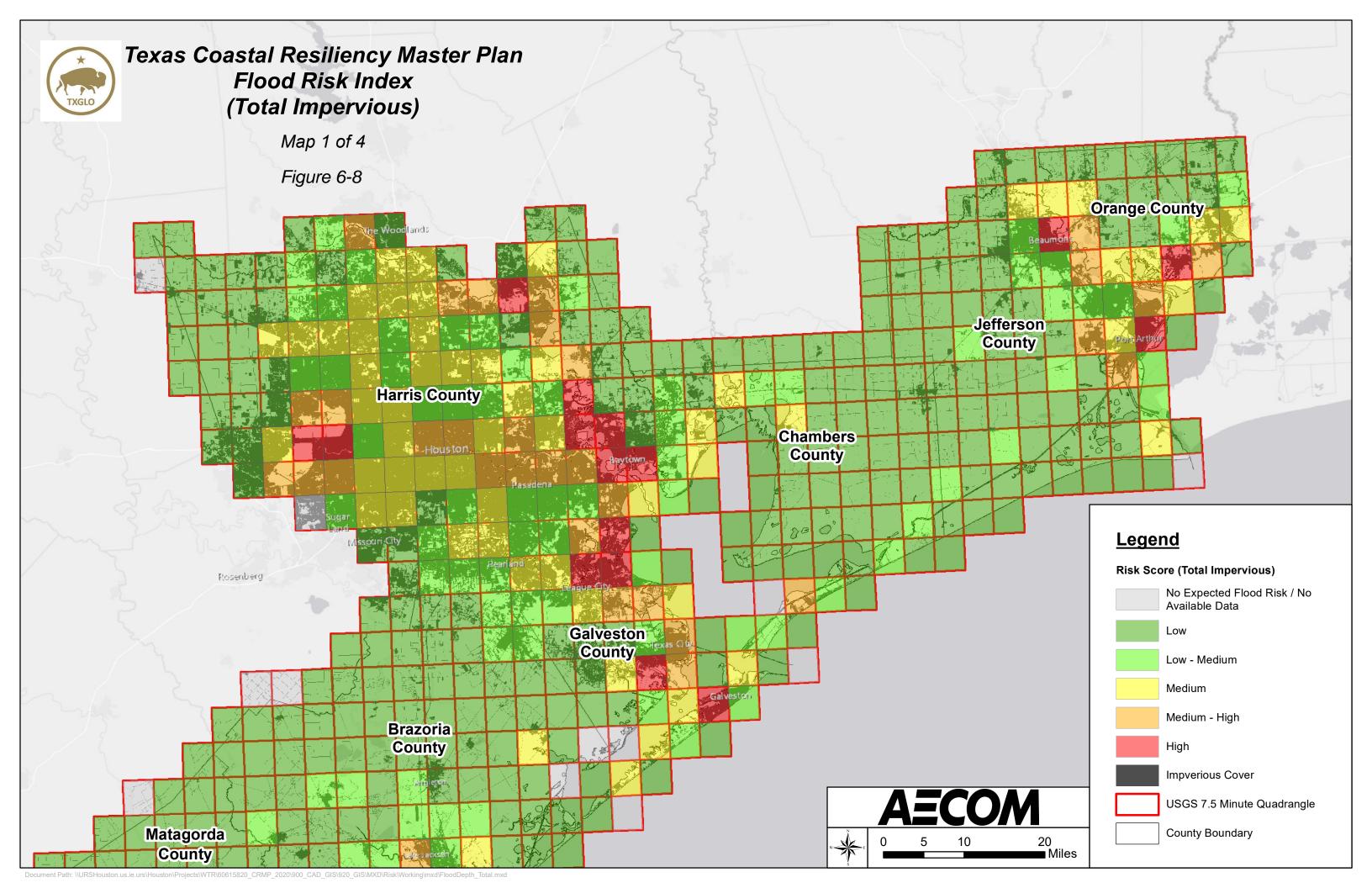
FEMA has developed a <u>National Risk Index</u> with a similar concept that includes 18 natural hazards, such as hurricanes, heat waves, earthquakes, and volcanic activity. FEMA's risk index includes expected annual loss, social vulnerability, and community resiliency to represent the potential for negative impacts resulting from natural hazards. The datasets can be viewed as a complete index, where the Risk Index = Expected Annual Loss x Social Vulnerability ÷ Community Resilience, or as individual components. While not specifically used for this process, FEMA's National Risk Index concept is similar in kind and may be able to provide additional information to support risk identification at the county level for GLO planning purposes.

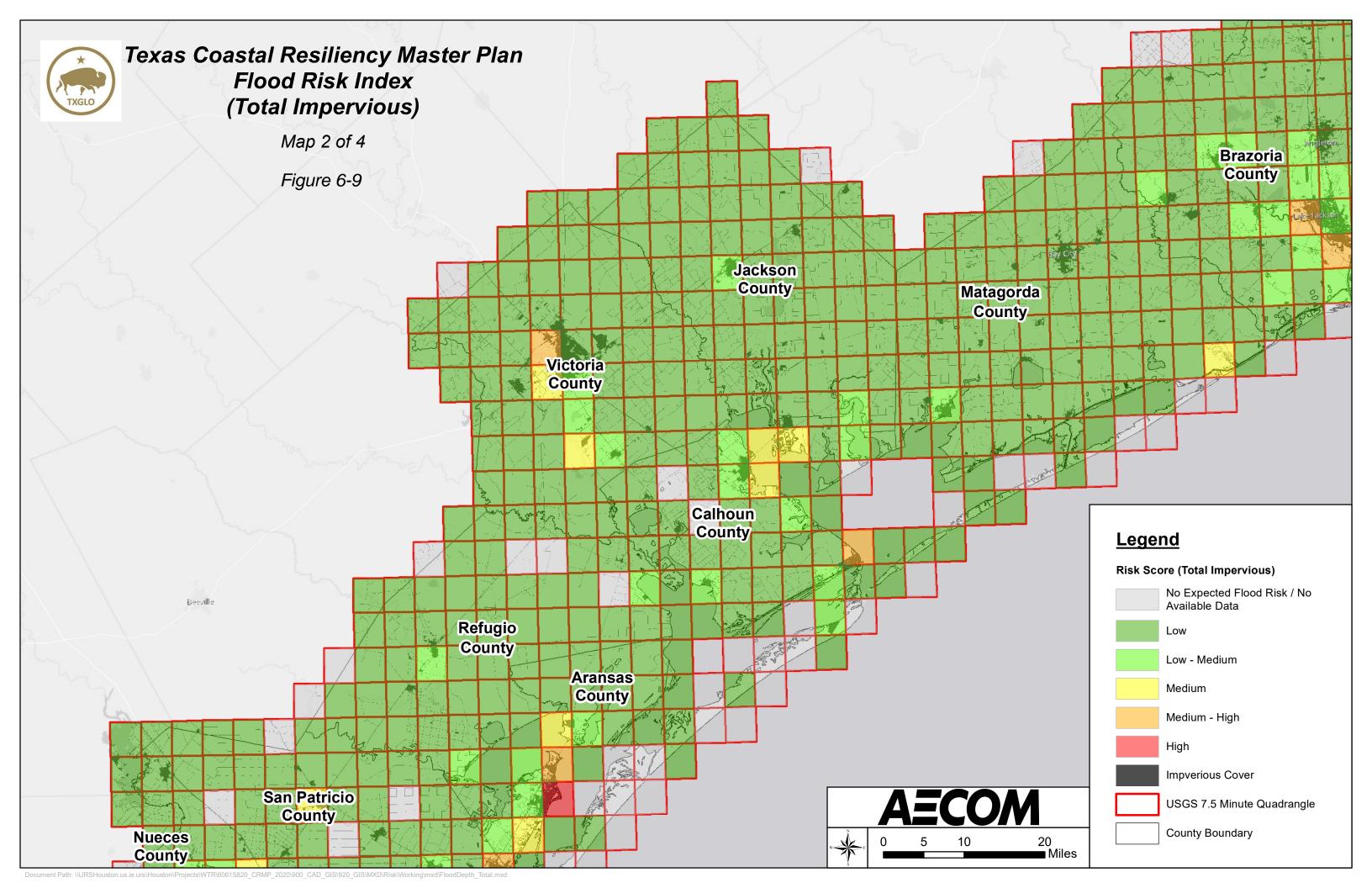


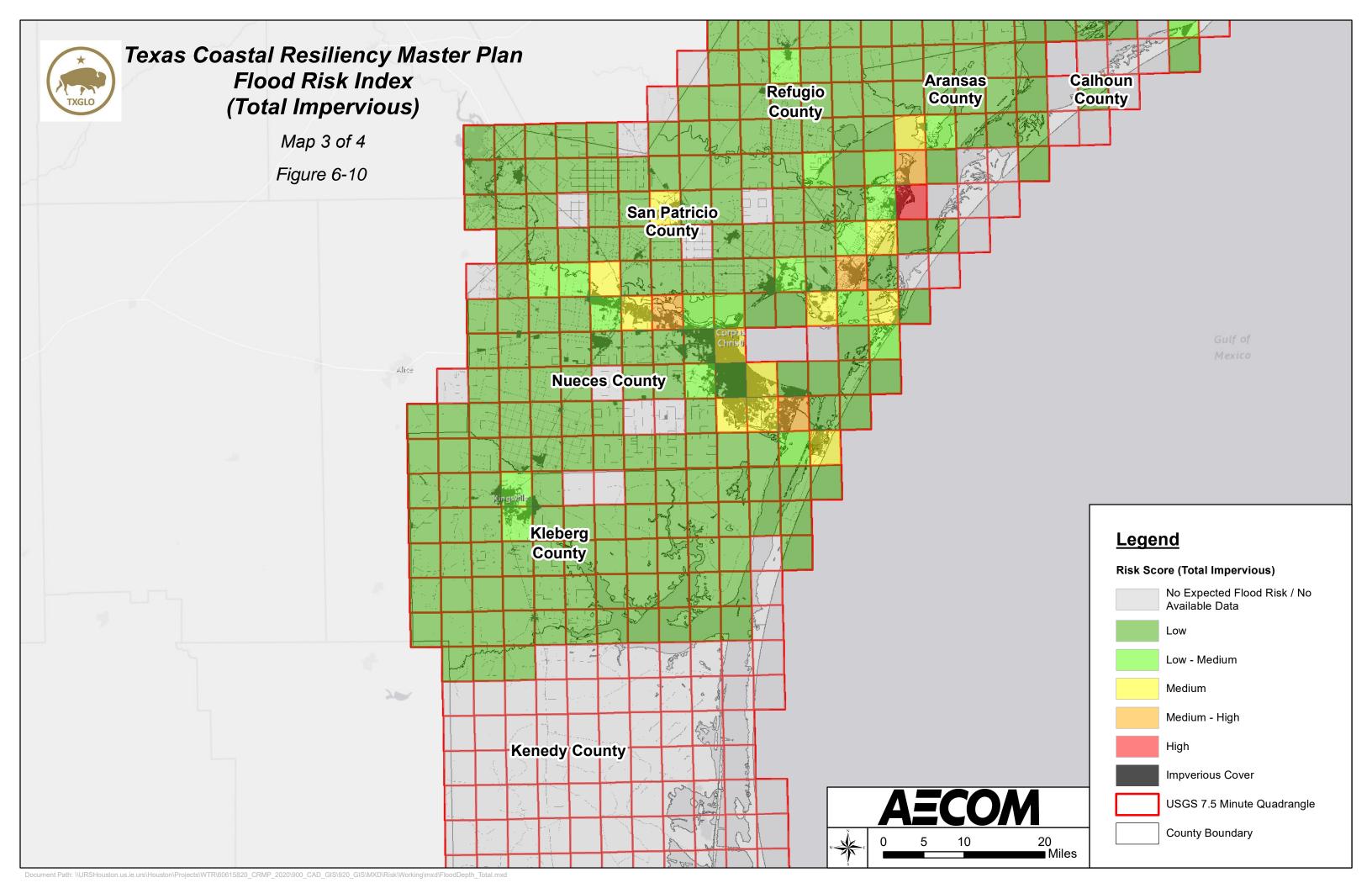


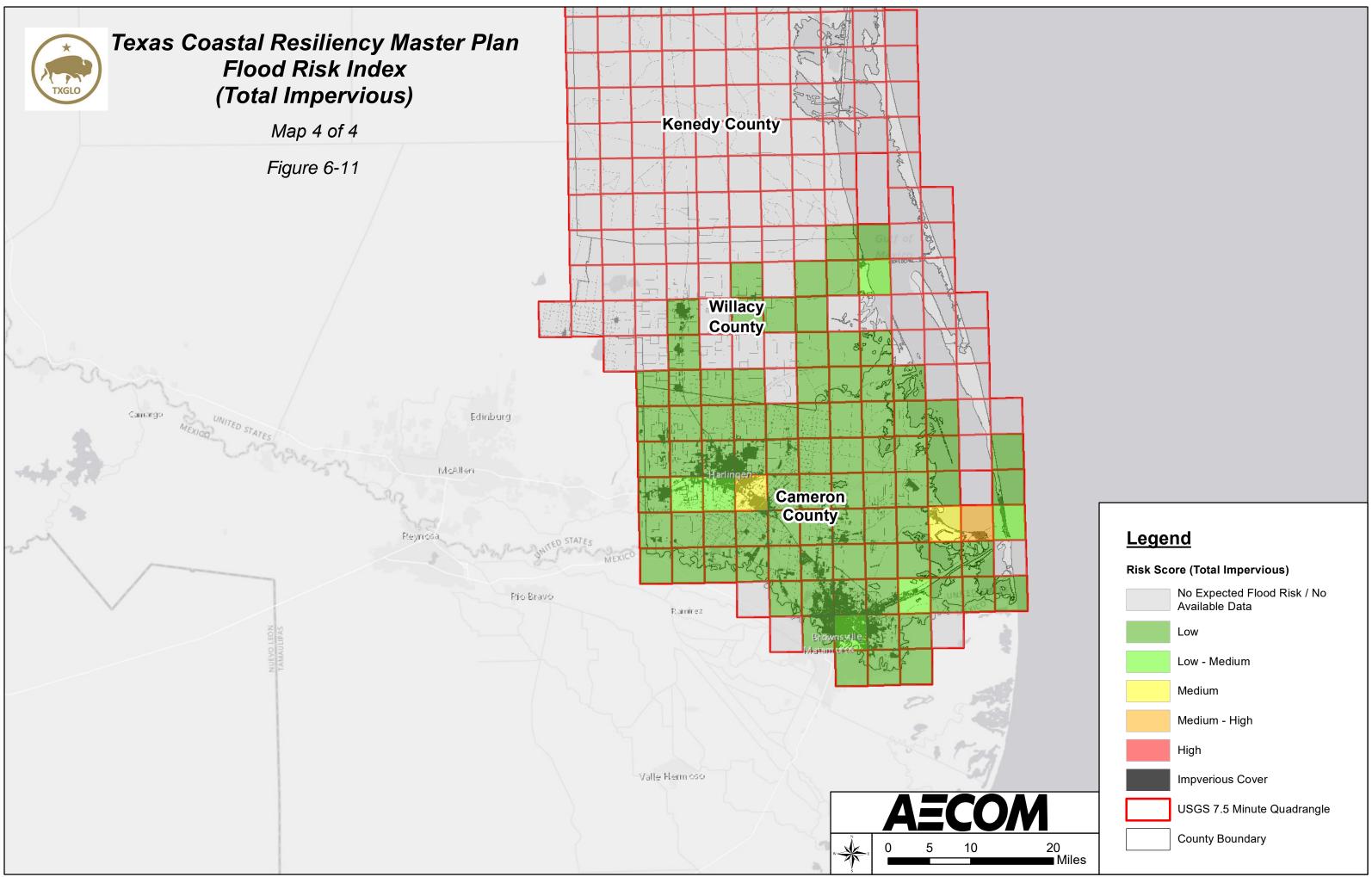


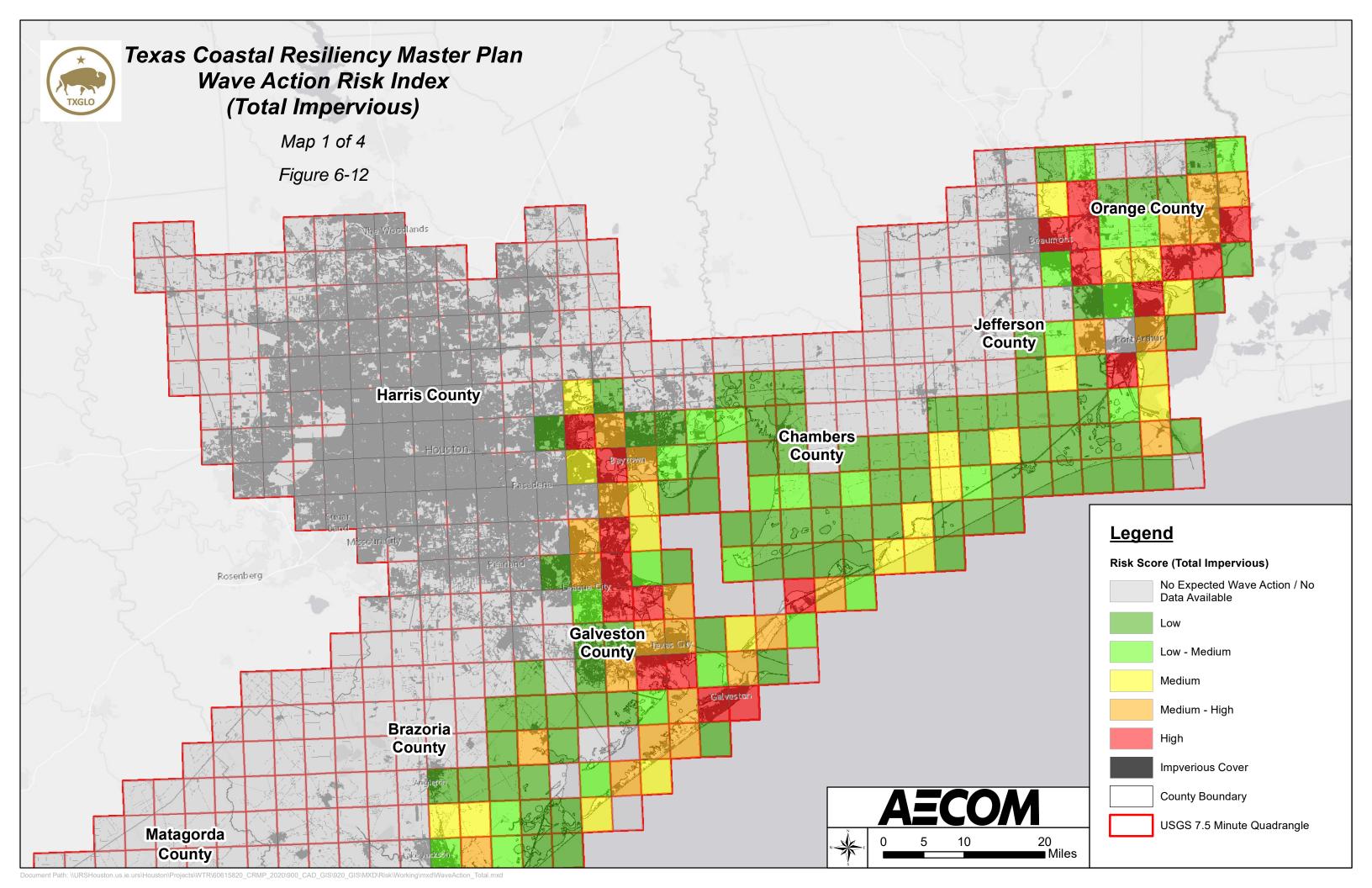


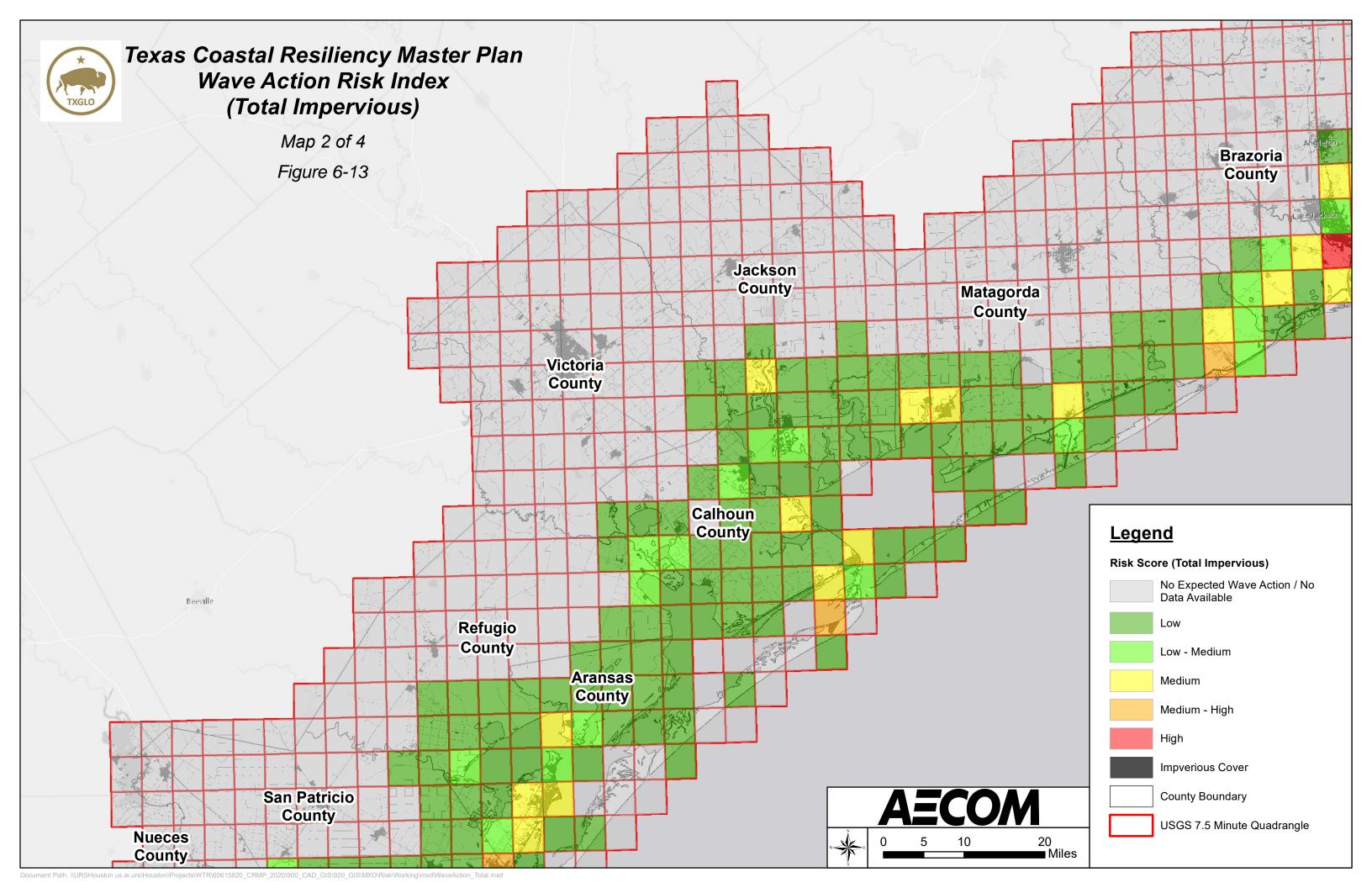


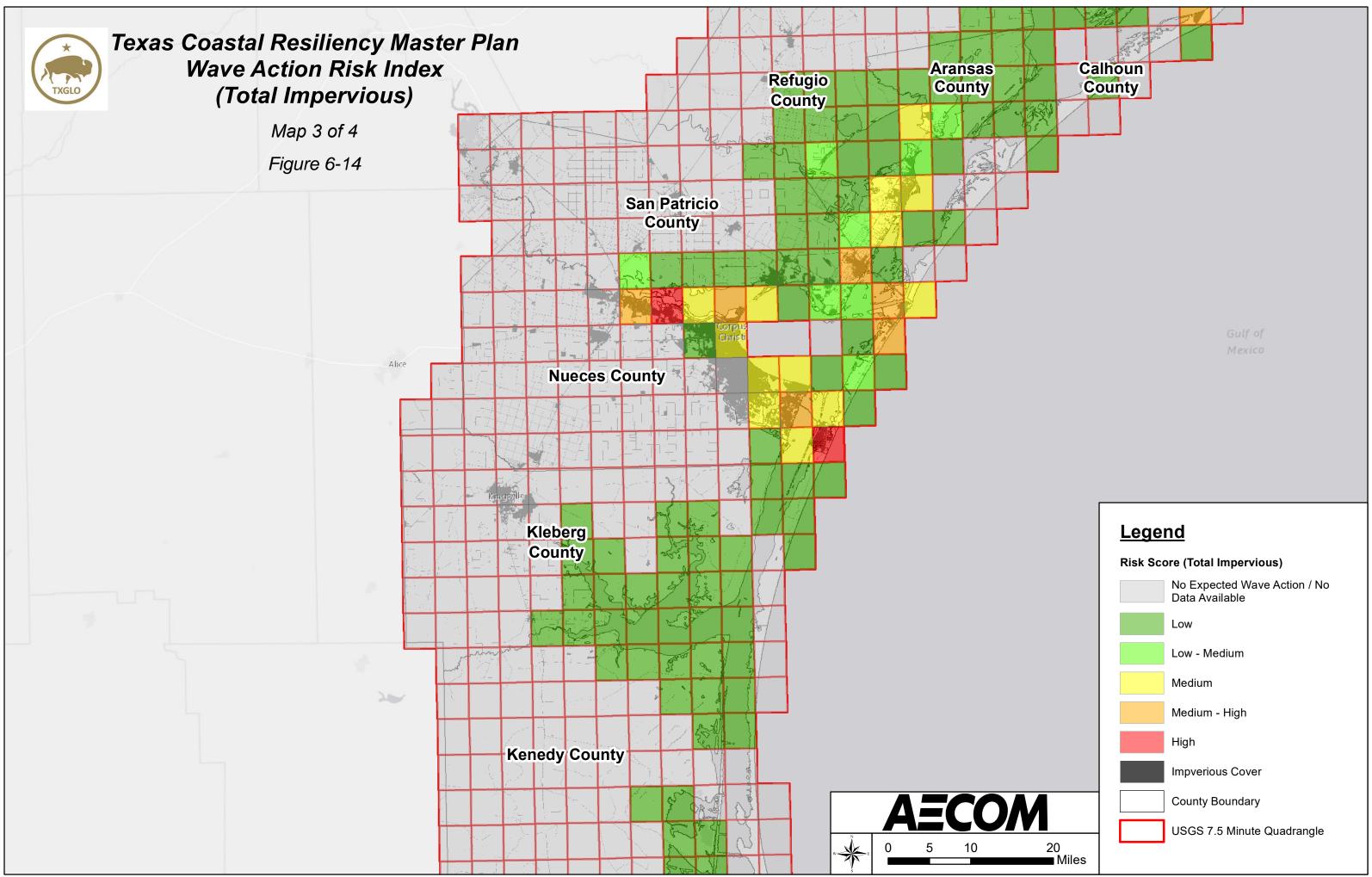


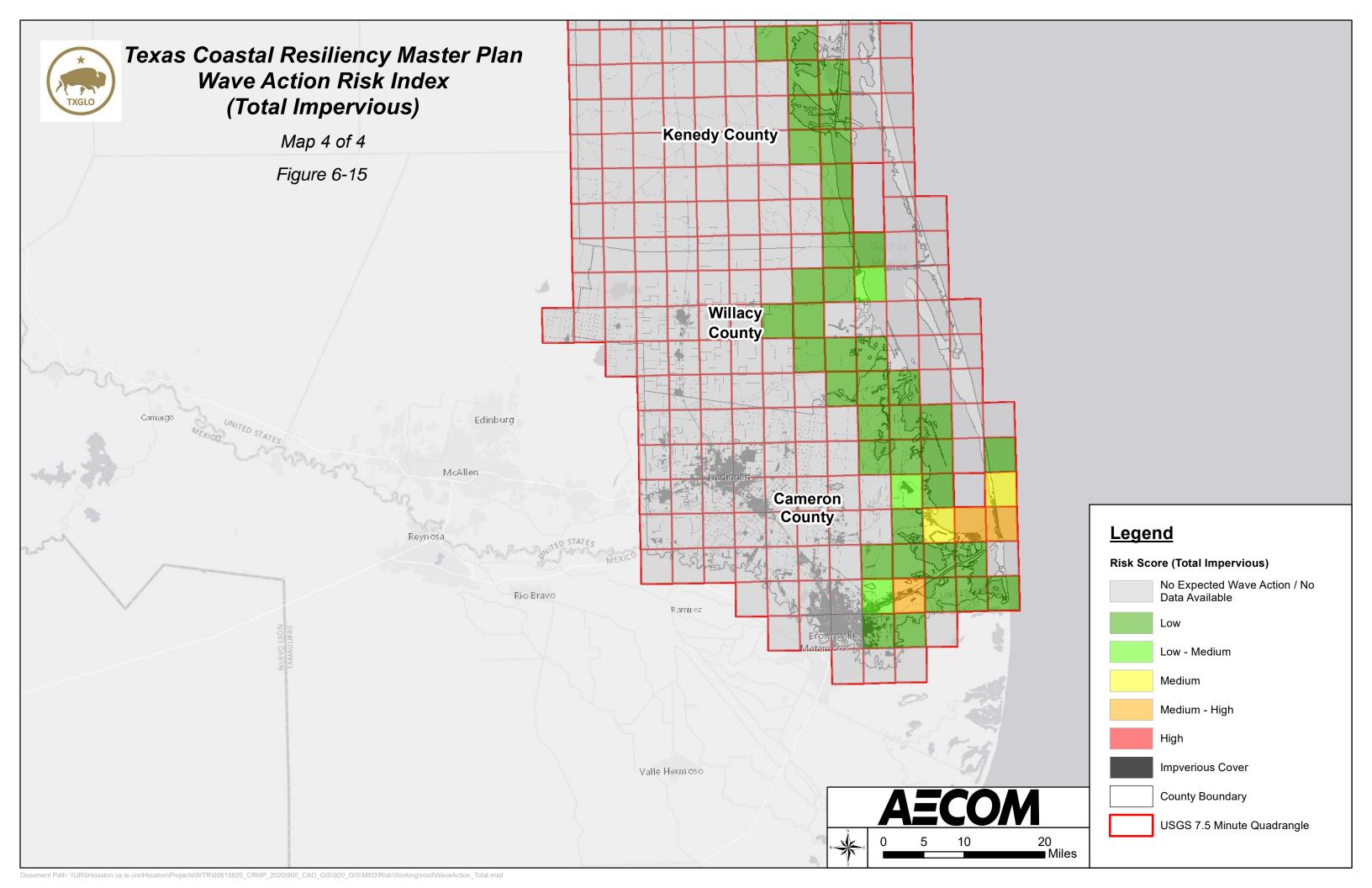












# Step C - Value of Ecosystem Services

Step C will aid a project proponent in describing the benefits of the ecological components of the proposed project. This will be done by characterizing the project by its main ecosystem service functions, such as habitat, biodiversity (species richness), primary productivity, provisioning services, and carbon sequestration. When data is available, quantified benefits may be transferred to the project based on regionally specific monetary valuations of the benefits of ecosystem services.



# **Ecosystem Services Provided by Projects Appropriate for Hazard Mitigation Funding**

## **Background**

This document discusses the development of an Ecosystem Services (ES) scoring tool that can be used to compare the benefits provided by nature-based projects that are included in the Texas Coastal Resiliency Master Plan (TCRMP) or are proposed coastal resiliency projects through other means. This scoring tool will be part of a larger process to prioritize or develop coastal Nature-based Solutions (NbS) projects suitable for hazard mitigation funding. The larger template will highlight projects that incorporate NbS and Green Infrastructure (GI) into their design, as well as underscore the ecosystem services they provide. This document will explore a potential approach to developing this novel ES tool for which no framework currently exists. The tool aims to help Texas General Land Office (GLO) planning staff and project proponents determine which ecosystem services can be provided by a proposed project and find alternative funding sources for projects with NbS and GI components.

Nature-based Solutions (NbS), as defined by the International Union of the Conservation of Nature (IUCN), are "Actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits." (IUCN 2021)



AECOM developed an initial Hazard Mitigation Eligibility Funding Score (HMEFS) scoring template in July 2020 and outlined a simple strategy to systematically score projects to identify projects that have a focus on NbS and GI and are likely to be appropriate for hazard mitigation funding. The HMEFS scoring template considered:

- Whether the project was considered a hazard mitigation project,
- Ecosystem service categories provided by the project,
- Project funding status, and
- Level to which the project is funded.

Green Infrastructure (GI) is an approach to mitigate the impacts of wet weather in a cost-effective and resilient manner that benefits communities. As defined by Section 502 of the Clean Water Act GI is "...the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters."(EPA 2021)

A revised and expanded ES scoring tool is presented here (Attachment A, Table 7-15), which incorporates feedback from the September 15, 2020 Technical Working Group meeting.



This scoring tool will assume that the project proponent has already used the Risk Index to determine if the project is located in an area that may be more suitable for hazard mitigation funding based on the level of risk to the specific vulnerability. As stated in Step B, some locations do not have an associated level of risk, either due to a lack of data for that specific vulnerability or there is no risk anticipated for that location. These locations may not be suitable for hazard mitigation funding at this time and should be evaluated on a case by case basis.

This document describes the development of the ES Score and defines the ecosystem services ranking system that will be used to assess projects. Four ecosystem services types are assessed – regulating, supporting, cultural, and provisioning – as described in further detail below.

## **Objective**

The ES Score will serve as a high-level planning tool for Texas GLO planning staff and project proponents. Primary objectives of developing the ES Score include:

- This tool will be used by GLO planning staff to identify coastal resiliency projects that incorporate NbS into their designs and may be appropriate for hazard mitigation funding opportunities. The tool should highlight those projects determined to be appropriate for hazard mitigation funding over projects that are less appropriate.
- Help project proponents identify ecosystem service benefits that can potentially be provided by their projects. Project proponents can use the provided information on ecosystem services to further support and strengthen their hazard mitigation grant applications.

#### **Texas Coastal Habitats of Interest**

NbS and GI design draw on relevant features of natural habitats for their design concepts. A range of coastal habitats exists along the Texas coastline that provide important economic benefits and ecosystem services that directly and indirectly benefit human life. The following habitats are the primary habitats considered in the TCRMP (for detailed habitats descriptions consult the TCRMP: TECHNICAL REPORT 2019):

- Coastal wetlands (saltwater, freshwater marshes, and mangroves)
- Coastal prairies
- Coastal bottomland forests
- Seagrasses
- Beaches and Dunes
- Oyster reefs
- Rookery islands

## **Ecosystem Services Scoring Overview**

The ES scoring system includes four ecosystem service categories: regulating, supporting, cultural and provisioning services. These ecosystem service categories are arranged in a set



order of priority within the scoring sheet (see Attachment A, Table 7-15). The order is determined first by relevance to hazard mitigation funding requirements, secondly, by importance in supporting general ecosystem functioning, and thirdly, by the provision of additional co-benefits that benefit local communities. This listed sequence of ecosystem service categories determines the weighted scores that are assigned to each category. Ecosystem services most relevant to hazard mitigation funding will have a higher weighted score, followed by supporting services that will have a moderately weighted score and, finally, the additional co-benefits obtained from cultural and provisioning services will have the lowest weighted score.

## **Limitations Specific to Ecosystem Scoring Classifications**

In addition to categorizing the four types of ecosystem services relevant to hazard mitigation funding requirements, each category is further classified by habitat of interest and scored as high, moderate, or low depending on the weight of benefits provided. This ES scoring tool is complex and broad in nature to encompass the intricacies of valuing ecosystem services which are specific to each habitat and ecosystem service category. Since this work is relatively new in terms of supporting literature, the scoring is based on, and takes into account, local Texas coast data whenever possible. However, Texas coast data was limited (or insufficient) for certain habitats of interest, in which case the search was expanded to the Gulf Coast and national and international studies to bolster the reasoning for the rank selected. Average metrics were obtained from the literature for each habitat and respective ecosystem service based on relevant and available data and used to divvy the habitats into their respective ranking class.

A few nuances to consider for the scoring process include (1) the high ranking may encompass a broader range of benefits when compared to the moderate and low rankings if the habitat was identified as a highly productive ecosystem in the literature. Habitats that scored at the moderate/high margin and were considered highly productive were bumped into the high ranking. (2) Monetary values were not developed for each of the ecosystem services, and, rather, draw upon the available literature for this scoring tool.

## **Ecosystem Service Categories**

**Regulating services** are essential in the maintenance of ecological processes and life-support systems for human wellbeing (Montagna et al. 2011). They are the primary focus of hazard mitigation funding. For this reason, they occur first in the sequence and are given the highest weighted score. (*Note: One regulating service not relevant to hazard mitigation funding is similarly included, namely carbon sequestration. More details for its inclusion and how it will be scored can be found in the regulating services score section*).

The remaining three ecosystem service categories are not priorities of hazard mitigation funding streams but do provide important co-benefits to both the environment and local communities. Capturing these co-benefits is important so that GLO planning staff and project proponents can have better opportunity to secure project funding.

**Supporting services** are essential to stable ecosystem functioning; without these services, the habitat would not exist and provide further benefits to communities through cultural and provisioning services. As supporting services are fundamental to ecosystem functioning, the



score given to this category is weighted more than the score given to cultural and provisioning services but weighted less than the score given to regulating services.

**Cultural services** enhance the emotional, psychological, and cognitive well-being of communities and **provisioning services** provide essential raw materials and resources (Montagna et al. 2011). Both these ecosystem services benefit communities living along the coast. However, at present, these benefits are not readily quantified in current hazard mitigation funding stream applications. For this reason, cultural and provisioning services are placed in third and fourth place in the ES scoring sheet. There is no specific reasoning for their sequence of being in third and fourth place. Cultural services are listed with providing two ecosystem services while the three provisioning services listed will be considered as one ecosystem service under provisioning services (for more details see Provisioning Services subsection). Each of their ecosystem services are given the same weighted score.

Within each ES category, ecosystem services that are considered most relevant are listed and ranked (see Table 7-1 for the ecosystem services considered under each ecosystem service category). Each of these services are ranked on a qualitative scale of low, moderate, or high and each ranking is equated to a set score. To assist a project proponent or planner select the most applicable qualitative ranking, definitions for each of the scoring ranks are discussed in further detail below (see Regulating Services Score and Co-benefits Score sections).

Not all ecosystem services that could be potentially provided by a habitat will be included in the scoring and ranking system but only those that are the most relevant to the objectives of this document. Brief descriptions of additional services will be provided, allowing project proponents to include those ecosystem services in their grant application narratives. Possible additional ecosystem services offered will be included after the Provisioning Services subsection but will not be discussed in detail.

## **Total Ecosystem Services Score**

The total ES score will be comprised of two scores (Table 7-1):

- The regulating services score will be a total score of all regulating services and
  program alignment questions relevant to hazard mitigation funding and will be a
  percentage score out of 16. The higher the score, the more likely a project will be
  targeting the goals of hazard mitigation funding requirements and will be appropriate
  for those funding streams.
- The co-benefits score will include the remaining ecosystem service categories: supporting, cultural and provisioning services, as well as regulating services not relevant to hazard mitigation funding requirements and will receive a percentage score out of 11. The co-benefits score will highlight potential additional ecosystem services projects can provide that do not directly impact hazard mitigation. Ecosystem services provided are fixed by habitat type.



Table 7-1: Regulating services score and co-benefits score composition detailing the ecosystem services listed and ranked under each score (for more information of each score, see their respective sections)

-	Regulating services score  Regulating services Score		Co-benefits score							
R			Regulating services	Score	Supporting services	Score	Cultural services	Score	Provisioning services	Score
	Storm surge/flooding protection	5	Carbon sequestration	1.5	Habitat	1.5	Ecotourism	1	Fisheries	
(	Erosion control/shoreline stabilization	5			Species richness (and Listed species and critical habitat)	3.5	Recreation	1	Grazing	1
F	Project Alignment Questions	6			Primary Productivity	1.5			Timber	
е	16		11							

## **Scoring Limitations and Assumptions**

- For the co-benefits score, the ecosystem services provided are specific to a habitat type (they are fixed by habitat type) and not to a project site. Some habitat types provide more ecosystem services than others. Consequently, those habitats providing more ecosystem services will score higher than habitats providing less. Planners should be cautious in using this score so as not to prioritize and support only the higher-scoring habitats.
- The provision of these ecosystem services assumes that each of the projects will result in healthy and fully functioning habitats, functioning at their highest ecological potential, and delivering all stated ecosystem services. This, however, may not necessarily be the case, as it may take many years for a newly created habitat to become fully functioning.
- Some habitats have limited to no studies evaluating specific ecosystem services. This
  has made it challenging to comprehensively assess a habitat's potential in providing
  ecosystem services relative to other habitats where more information is available. For
  instance, there were no studies found for estimating carbon sequestration rates or net
  primary productivity rates on rookery islands.
- It is important to consider the functional value of the habitat provided. For instance, from a hazard mitigation funding perspective, a 2-acre wetland providing shoreline stabilization in an urban environment provides more benefit by protecting the local community to coastal hazards compared to a 50-acre wetland in a rural setting, which may not protect any local communities. The Risk Index attempts to provide some clarification for this point by cross-mapping vulnerabilities with impervious, developed areas.
- Differentiation of ecosystem services between restored and natural habitats is not the intent of this scoring tool. It is a limitation of this work, which is currently meant to



describe the potential range of benefits that habitats of interest can provide in coastal Texas. Ecological restoration ideally results in enhanced ecosystem services to a healthy state but does take time and generally large investments for success (Palmer and Filoso 2009). There is evidence that asset values of restored coastal habitats are lower than conserving original habitats and often fall short of recovering the full suite of ecosystem services when compared to the original (or natural) habitat (Barbier et al. 2011).

## **Regulating Services Score (Total Score 16)**

Regulating services are the result of the regulating processes of a given habitat and are essential to maintaining ecological processes and life-support systems for human wellbeing (Montagna et al. 2011). Examples of the benefits of regulating services include storm surge protection, shoreline erosion control, carbon sequestration, water filtration, air quality, and nutrient control. For the purposes of this scoring system, only regulating services relevant to hazard mitigation funding will be considered. Hazard mitigation funding prioritizes the benefits obtained from regulating services when compared with supporting, provisioning, and cultural services, as they can most directly prevent and reduce damages to properties and infrastructure. Additionally, hazard mitigation funding focuses on the benefits derived primarily from **storm surge/flooding protection** and **erosion control/shoreline stabilization**. For this reason, these are the two priority regulating services that are considered in this scoring system and are ranked. They also receive the highest weighted score.

**Carbon sequestration**, although not a hazard mitigation funding priority, has also been added to regulating services. There are currently third-party efforts underway to develop a carbon tracking system for Texas coastal habitats. These efforts are still in their infancy; however, keeping track of the carbon sequestration potential of TCRMP projects may prove useful once the carbon tracking system is complete. However, carbon sequestration does not score as high as the other two regulating services, as it is not a hazard mitigation funding priority. For this reason, it will also be grouped and scored under the co-benefits score (see Table 7-1).

## **Program Alignment Questions**

To begin scoring regulating services, a series of questions will be answered. Each question is scored as a binary score of yes (score 2) and no (score 0). The questions include:

- Is the project considered a pre- or post- 'hazard mitigation' project (targeting hazards such as flood mitigation, coastal storm surge/wave protection, erosion control and/or shoreline stabilization) for a developed area?
- Is the proposed project located in a vulnerable coastal zone as assessed by the 'Risk Index' (is the project located in an area designated as Medium, Medium-High, or High Risk for flood depth, land loss, or wave action)?
- Does the project incorporate relevant NbS features derived from the aforementioned Texas coastal habitats to address an expected hazard (e.g., using coastal wetlands features to provide storm surge protection)?

Thereafter, each regulating service will be assessed and scored as described below.



## **Regulating Services**

## **Storm Surge/Flooding Protection**

Coastal flooding is a short-term direct impact that is caused by storm surge, unusually high tides, and strong winds. Storm surges will be more severe and coastal flooding will occur more frequently as sea levels rise and the frequency and intensity of storms increase. Communities, infrastructure, and natural environments along the Texas coast will become increasingly vulnerable to the impacts of coastal flooding.

## Developing the Ranking System

Storm surge/flood protection can be provided when the habitat introduced, protected, or enhanced by a project provides a buffer to incoming waves or flood waters. When a project/habitat provides significant storm and/or flooding protection, the project will rank 'High' as shown in the *ranking system* below. If a project/habitat provides low to moderate storm surge protection, the project will rank 'Moderate'. If a project/habitat provides little to no storm surge/flooding protection it will rank 'Low'. Classifications for each habitat type are shown in Table 7-2.

Table 7-2: Storm Surge/Flooding Protection Ranking by Habitat Type

Habitat Type		Protection Provided	Habitat Ranking
Coastal freshwater marshes <sup>1</sup>	Reduces flood	Habitat % of subwatershed by area*	
	inundation	> 20%	High
		10-20%	Moderate
		< 10%	Low
Saltwater marshes <sup>1</sup>	Reduces	Habitat width at shoreline, w	
	Waves	w > 30 ft	High
		10 ft ≤ w ≤ 30 ft	Moderate
		10 ft < w	Low
Mangroves		Reduces waves	Moderate
Coastal prairies		Reduces waves + flood inundation	High
Coastal bottomland forests		Reduces waves	Moderate
Seagrasses		N/A	Low
Beaches		Reduces waves + flood inundation	High
Dunes (vegetated)		Reduces waves + flood inundation	High
Oyster reefs		Reduces waves	Moderate
Rookery Islands		N/A	Low

<sup>\*</sup>First, identify your subregion (subwatershed) here: <a href="https://water.usgs.gov/wsc/map\_index.html">https://water.usgs.gov/wsc/map\_index.html</a>. Then, using the 8-digit number, look up its area here: <a href="https://water.usgs.gov/GIS/huc\_name.html">https://water.usgs.gov/GIS/huc\_name.html</a>. To compute the habitat percentage of the subwatershed by area, divide the total square miles of habitat generated by the project over the total subregional area.

## Ranking System

<sup>&</sup>lt;sup>1</sup> Minnesota Board of Water and Soil Resources, 2010



**Low** – project provides little to no storm surge/flooding protection (no wave action reduction or flood inundation extent reduction) (Score = 0)

**Moderate** – project provides low to moderate storm surge/flooding protection (characterized by wave action reduction or limiting flood inundation extents, but not both) (Score = 3) **High** – project provides moderate to significant storm surge/flooding protection (characterized by reduction of wave action and flood inundation extents) (Score = 5)

#### **Erosion Control/Shoreline Stabilization**

Coastal erosion occurs when physical processes such as strong wave action, relative sea level rise, and coastal flooding wear away at the sand and sediment found along the coast. This results in land loss and as shorelines retreat infrastructure located further inland become more vulnerable to flooding as the buffer zone protecting them from coastal processes is reduced. In the U.S., land loss damage to coastal properties due to coastal erosion is estimated to be \$500 million per year (CRT 2019).

Erosion control/shoreline stabilization is provided when a project provides a buffer to incoming waves, thereby reducing wave heights to reduce erosion or trapping sediment to maintain the integrity of the shoreline (Table 7-3).

Table 7-3: Erosion Control/Shoreline Stabilization Ranking by Habitat Type

парітат туре	Protection Provided	nabitat Kalikilig
Coastal freshwater marshes	Retains sediment	Moderate
0 1: .		

Coastal freshwater marshes	R	Retains sediment		
Saltwater marshes	Creates buffer +	Habitat width at shoreline, w		
	retains sediment	w > 30 ft	High	
		w ≤ 30 ft	Moderate	
Mangroves	Creates b	uffer + retains sediment	High	
Coastal prairies	Creates b	Creates buffer + retains sediment		
Coastal bottomland forests	Creates b	Creates buffer + retains sediment		
Seagrasses	R	Retains sediment		
Beaches	Creates b	uffer + retains sediment	High	
Dunes (vegetated)	Creates b	Creates buffer + retains sediment		
Oyster reefs		Creates buffer		
Rookery Islands		N/A*		

<sup>\*</sup>Depending on the location of the island, some erosion control may be provided. This should be assessed on a site-by-site basis by a qualified professional.

#### Ranking System

**Low** – project provides little to no erosion control/shoreline stabilization (Score = 0) **Moderate** – project provides low to moderate erosion control/shoreline stabilization by creating a buffer zone or providing/retaining sediments at a shoreline, but not both (Score = 3) **High** – project provides moderate to significant erosion control/shoreline stabilization by creating a significant amount of buffer zone and providing/retaining sediments at the shoreline (Score = 5)



## **Co-benefits Score (Total Score 11)**

Incorporating NbS and/or GI into hazard mitigation projects can provide added benefits not always immediately apparent. These secondary benefits, also known as co-benefits, can have cascading effects and consequently contribute to the environmental, social, and economic well-being of a region. By considering co-benefits, there may be additional opportunities to access novel funding sources and strengthen funding applications. It is important to note that ecosystem services are fixed by habitat type, resulting in some habitats providing more ecosystem services than others.

## **Regulating Services**

## **Carbon Sequestration**

Carbon sequestration is the ability of vegetation (above and below ground) and soils to store or capture atmospheric carbon dioxide. Coastal habitats (such as coastal marshes, mangroves, and seagrasses) play an integral role in sequestering carbon dioxide (termed 'blue carbon') and although they cover a significantly smaller area than terrestrial ecosystems, they are able to sequester carbon at up to ten times greater than terrestrial habitats, such as forests, on a per area basis (RAE 2021). Coastal habitats store a greater majority of carbon in their soils, where it is able to remain sequestered for centuries or more, compared to terrestrial forests (Pidgeon 2009). This provides great incentive to protect and restore these coastal systems, as they play a pivotal role in balancing out the global carbon budget, thereby reducing atmospheric carbon.

The rate and potential of a habitat to sequester carbon is dependent on a variety of factors: amount of vegetation present, location, and biological and physical processes such as soil microbes, sedimentation rates, and flooding frequency. Consequently, carbon sequestration rates can be highly variable among coastal habitats types, especially among the habitats of interest for the ES tool, and habitats can act as either carbon sinks or even as carbon sources (by emitting methane gas). For example, highly vegetated habitats such as marshes have greater potential to store carbon in vegetation compared to sparsely vegetated habitats, such as dunes and beaches. Additionally, marshes that are adjacent to saltwater have a greater potential to sequester carbon compared to freshwater/brackish marshes, which are more likely to emit methane. This varying ability of a marsh to be a 'sink' versus a 'source' of carbon and methane is due to the presence of soil microbes. Soil microbes in a saltmarsh utilize the sulfate ions available in seawater to create energy. Those same soil microbes present in a freshwater/brackish marsh will have fewer sulfate ions available, and therefore rely on other processes to create energy that then produce methane (MBL - University of Chicago 2017).

## Developing the Ranking System

In order to rank a habitat's potential in sequestering carbon, it is first necessary to determine a habitat's annual carbon sequestration rate (Table 7-4). Carbon sequestration rates can be measured in terms of pounds (lbs.) of carbon (C) sequestered per unit area (acres - ac) per year (yr) (i.e., lbs. C/ac/yr). A literature search was conducted to find studies that have attempted to quantify this rate. The literature search was initially focused on studies conducted within Texas and/or along the Gulf of Mexico on each of the habitats of interest. If local studies were not found, national and/or international study examples were used. As carbon sequestration rates can vary even within a specified habitat type, multiple studies were consulted (~2-4 studies per habitat type were collected where available) and a composite



Null/No data

average annual carbon sequestration rate per habitat type was calculated (see Attachment B, Table 7-16).

Subsequently, each composite average annual carbon sequestration rate per habitat type was compared across the habitats of interest to determine and categorize a habitat's ability to sequester carbon (carbon sequestration potential) into a low, moderate, and high ranking (Table 7-4).

Table 7-4: Average Annual Carbon Sequestration Rates and Ranking by Habitat Type\*

## Average Annual Global Carbon Sequestration Rate

Ibs. C/acre/yr **Habitat Type Habitat Ranking** Coastal freshwater marshes ~1,500 High Saltwater marshes 3,187 High 3,359 High Mangroves Coastal prairies 1.037 High Coastal bottomland forests 4,032 High Seagrasses 1,198 High Beaches N/A Null/No data 535 Dunes (vegetated) Moderate Carbon sink: subtidal sandflat reefs 892 lbs C/ ac/yr Carbon sink: Oyster reefs Low saltmarsh-fringing oyster reefs 1,160 lbs C/ ac/yr Carbon source: Intertidal sandflat reefs -6,300 lbs C/ ac/yr

No Data Available

Using the average annual carbon sequestration rates obtained for each habitat, the habitat ranking was categorized and scored as follows:

## Ranking System

Rookery Islands

Null/No data - Score = 0

**Low** – habitat rate of carbon sequestration is low. Low rate = ≤ 100 lbs./ac/yr (Score = 0.5) **Moderate** – habitat rate of carbon sequestration is moderate. Moderate rate = 100-999 lbs./ac/yr (Score = 1)

**High** – habitat rate of carbon sequestration is high. High rate = ≥1,000 lbs./ac/yr (Score = 1.5)

<sup>\*</sup> Average annual carbon sequestration rates were calculated from collected studies see Attachment B Table 7-16 detailing the comprehensive list of studies consulted. See Attachment C for habitat descriptions discussing the research studies consulted and additional rationale for habitat ranking (specifically for beaches and oyster reefs).



## **Supporting Services**

Supporting services are fundamental in allowing general, stable ecosystem functioning. The core services include habitat provision, biodiversity, soil formation, nutrient cycling, and primary production. For the purposes of this scoring system, the core services of **habitat provision**, **biodiversity** (i.e., species richness), and **primary production** were considered to be the most suitable to rank and score.

## **Habitat Provision**

Habitat refers to the natural home or environment of a species. Within its habitat, a species will find the suitable environmental conditions it requires to survive. The basic tenets of ecology state that the larger the habitat and the more area available for species, the greater the benefit to the species. Therefore, the amount of habitat created and enhanced through a project's efforts will be the determining factor in developing the ranking system outlined below.

## Developing the Ranking System

A review of habitat sizes of current TCRMP projects was completed to help guide the categorization of habitat sizes under low, moderate, and high rankings. Project Cost Templates for the 2019 TCRMP projects were reviewed for projects that incorporated nature-based features into their design. The area (acres) of created or enhanced habitat was recorded for each of the habitats types and summary statistics were calculated. The summary statistics were used as the primary baseline to guide establishing the class sizes for the ranking system (Table 7-5). The median was used as the focal point from which to base a generalized 'moderate' ranking as well as inform the 'high' ranking if the maximum range number was considered very high. The minimum range helped establish the 'low' ranking. However, where necessary, habitat sizes were modified based on engineering judgement and the planning team's experience with working with projects along the Texas coast.

A total of 73 TCRMP projects were found that included nature-based features into their design. Projects did not differentiate between the different types of wetlands; therefore, there is only one wetland category for this ecosystem service (namely, 'coastal wetlands'). There were no projects found that created or enhanced coastal bottomland forests and prairie habitat, and only one project enhanced/created seagrass habitat. Habitat sizes for these features were similarly estimated based on engineering judgment and the planning team's project experience. Beaches and dunes were considered as one habitat type for this ecosystem service as some projects enhanced both habitats, and area data were subsequently given for the entire beach/dune system.

Table 7-5: Summary Statistics for the Habitat types derived from acres of created/enhanced habitat by 2019 TCRMP projects

	Coastal Wetlands	Coastal Bottomland Forests	Coastal Prairies	Seagrass	Beach and Dunes	Oyster Reefs	Rookeries
n (number of samples)	43	0	0	1	9	10	10
Standard Deviation	815.1	-	-	-	124.2	38.7	29.6

Mean (acres)	364	-	-	14	69.9	26.8	28.3
Median (acres)	50	-	-	14	25	12.5	16.5
Mode (acres)	50	-	-	-	60	10	10
Minimum (acres)	0.25	-	-	14	3	1	5
Maximum (acres)	4,000	-	-	14	397	130	100

## Ranking System

Each ranking is specific to each habitat type (see Table 7-6)

**Low** - (Score = 0.5)

Moderate - (Score = 1)

**High** - (Score = 1.5)

Table 7-6: Habitat Acreage Ranking by Habitat Type

Habitat Type	High	Moderate	Low	
Coastal wetlands	≥100 acres	6-99 acres	≤ 5 acres	
Coastal prairie* ≥50 acres		6-49 acres	≤ 5 acres	
Coastal bottomland forests*	≥ 50 acres	6-49 acres	≤ 5 acres	
Seagrasses*	≥ 50 acres	11-49 acres	≤ 10 acres	
Beaches and dunes*	≥10 acres	4-9 acres	≤ 3 acres	
Oyster reefs	≥25 acres	6-24 acres	≤ 5 acres	
Rookery Islands	≥25 acres	6-24 acres	≤ 5 acres	

<sup>\*</sup>Habitat sizes estimated based on engineering judgment and planning team experience working with coastal resilience projects on the Texas coast.

## **Biodiversity (Species Richness)**

Biodiversity, which is short for biological diversity, refers to genetic, species, and ecosystem diversity within natural systems (ESA 1997). For the purposes of this scoring system and to maintain a high-level view on biodiversity, the focus will only be on species richness, which considers the number of species present within a habitat type. Species richness can be influenced by a habitat's size and/or its connectivity to other habitats (larger habitats generally have greater capacity to hold more species). It can similarly be influenced by habitat type (for example, coastal bottomland forests typically have greater biodiversity than a beach).

It is important to consider that since species richness can be a function of habitat type, it may not necessarily be a negative attribute if a habitat has low levels of species richness, as it is just the inherent capacity of that habitat. The aim of the scoring system would not be to prioritize the restoration or enhancement of habitats with higher species richness levels over those exhibiting lower levels—for example, beaches are equally important habitats to support



compared to bottomland forests. Many of the habitats with low species richness provide refuge for threatened and endangered (T&E) species and/or are listed as 'critical habitat' for T&E species. As such, the ranking system for species richness will be developed with second and third-tier rankings to be able include these additional factors. Therefore, unlike the other supporting services that score a total of 1.5, the total 'Species Richness' score is 4.

## **Developing the Ranking System**

The number of species (plants and wildlife) associated with each of the Texas coastal habitats were collected, recorded, and listed in Table 7-7. An online search was conducted to find species richness data per habitat of interest and sources, such as the Texas Park and Wildlife Department's <a href="Ecological Mapping Systems of Texas"><u>Ecological Mapping Systems of Texas</u></a> webpage, were consulted.

Table 7-7: Biodiversity (Number of Species) Associated with each Habitat Type and Ranking by Habitat Type

Habitat Type	Number of Species		Reference	Habitat Ranking
Coastal freshwater marshes	~512	Includes plants, birds, amphibians, reptiles, mammals, and fish species.	Mitsch and Gosselink 1993; Odum et al. 1984; TPWD 2021a	High
Saltwater marshes	~619	Includes plants, mammals, reptiles, amphibians, insects, and non-insect macroinvertebrate species.	USFWS 2019; TPWD 2021a	High
Mangroves	~1,300	Includes 628 species of mammals, birds, reptiles, fish, and amphibians.	USFWS 2019	High
Coastal prairies	~420	Includes plants and bird species.	TNC 2020	Moderate
Coastal bottomland forests	~1627	Includes trees and shrubs, woody vines, grasses and herbaceous plants, fish, reptiles, amphibians, birds, and mammal species	TEA 1995	High
Seagrasses*	hundreds of species depend are on this habitat type	Considers invertebrates (mollusks, crustaceans) fish, algae, turtles, and marine mammals	Reynolds et al. 2018	High
Beaches and dunes**	~650	Includes mammals, amphibians, birds, crustaceans, fish, mollusks, reptiles, and plant species	TPWD 2021a; NPS 2021	High
Oyster reefs	~300	Includes fish and invertebrate species.	Volety 2013	Moderate



Rookery Islands	26	Includes bird species	Hackney et al.	Low
		only.	2016	

<sup>\*</sup>No estimated 'number of species' found for seagrass meadows but as they are known 'biodiversity hotspots' they are ranked high (Reynolds et al. 2018).

Thereafter, comparing species number across habitat types the ranking system below was categorized as follows:

# Ranking System

**Low** – Number of species is low: 26 species. (Score = 0.5)

**Moderate** - Number of species is moderate: 300-499 species. (Score = 1)

**High** - Number of species is high: >500 species. (Score = 1.5)

For the second tier of ranking, the number of listed threatened and endangered species (plants and wildlife) for each habitat type was collected, recorded, listed and ranked in Table 7-8.

Table 7-8: Number of Listed Threatened and Endangered Species Associated with each Habitat Type and Habitat Ranking

Habitat Type	Number of Species	Species Common Name	Reference	Habitat Ranking
Coastal freshwater marshes	2	Black rail, whooping crane	TPWD 2021b	Low
Saltwater marshes	2	Black rail, whooping crane	TPWD 2021b	Low
Mangroves	2	Atlantic hawksbill sea turtle, smalltooth sawfish	TPWD 2021b	Low
Coastal prairies	3	Attwater's prairie chicken, black lace cactus, slender rush-pea	TPWD 2021b	Moderate
Coastal bottomland forests	74	Too many to list	TEA 1995	High
Seagrasses	4	Atlantic hawksbill sea turtle, green sea turtle, Kemp's Ridley sea turtle, smalltooth sawfish	TPWD 2021b	Moderate
Beaches and dunes (unvegetated to sparsely vegetated)	6	Atlantic hawksbill sea turtle, green sea turtle, Kemp's Ridley sea turtle, loggerhead sea turtle, piping plover, Rufa red knot	TPWD 2021b	Moderate
Dunes (vegetated)	1	Piping plover	TPWD 2021b	Low
Oyster reefs	3	Atlantic hawksbill sea turtle, green sea turtle, smalltooth sawfish	TPWD 2021b	Moderate

<sup>\*\*</sup> Due to limited data 'Beaches and Dunes' species richness estimate is based on species listed at the Padre Island National Seashore



Habitat Type	Number of Species	Species Common Name	Reference	Habitat Ranking
Rookery Islands	6 (birds only)	Black rail, northern aplomado falcon, piping plover, red-cockaded woodpecker, Rufa red knot, whopping crane	TPWD 2021b	Moderate

### Ranking System

**Low** – Number of T&E species is low: 0-2 species. (Score = 0.5)

**Moderate** - Number of T&E species is moderate: 4-6 species. (Score = 1)

**High** - Number of T&E species is high: >70 species. (Score = 1.5)

For the third-tier ranking, the rank will be binary and only give credit to habitats federally listed as 'critical habitat' (Table 7-9):

**Yes** = 0.5; **No** = 0

Table 7-9: Federally Listed Critical Habitats along the Texas Coast

Habitat Type	Listed as 'critical habitat'	Species of Concern Common Name	Reference
Coastal freshwater marshes	Aransas National Wildlife Refuge*	Whooping crane	ECOS-USFWS 2021
Saltwater marshes	Aransas National Wildlife Refuge*	Whooping crane	ECOS-USFWS 2021
Mangroves	Not listed		
Coastal prairies	Not listed		
Coastal bottomland forests	Not listed		
Seagrasses	Not listed		
Beaches and dunes (unvegetated to sparsely vegetated)	Yes	Piping plover	ECOS-USFWS 2021
Dunes (vegetated)	Not listed		
Oyster reefs	Not listed		
Rookery Islands	Not listed		

<sup>\*</sup>Only Aransas National Wildlife Refuge is listed as critical habitat for Whooping crane. Therefore, only coastal freshwater and saltwater marshes restored/constructed within the Refuge are eligible for points.

#### **Primary Production**

Primary production is the ability of green plants (and certain bacteria) to convert solar energy into biomass. Primary production supports most life on earth and drives the global carbon, nitrogen, phosphorous, and other nutrient cycles. Rates of primary production are habitat specific. For example: a sparsely vegetated beach/dune habitat will have less primary productivity than a heavily vegetated coastal wetland.



The total amount of energy produced by plants is termed Gross Primary Production (GPP); as plants use some of this energy for their own growth, not all the energy produced is available for other species. The difference between GPP and what plants use is what becomes available for other species to use and is termed Net Primary Productivity (NPP). Therefore, the primary productivity of a habitat is measured in rates of NPP, which is expressed as mass (grams, g) of dry weight of vegetation produced per square meter (m²) per year (yr) (i.e., g/m²/yr) or as mass of carbon per square meter (m²) per year (yr) (i.e., gC/m²/yr, where 1gC = 2g dry weight – Mitsch and Gosselink 1993; Duarte and Chiscano 1999; Duarte et al. 2011).

NPP is comprised of aboveground NPP, which is the annual net biomass production of flowers, fruits, leaves and leaf litter, twigs, branches, and stem growth and belowground NPP, which is root productivity. The latter can be difficult to measure and therefore in the literature it is common to find NPP described in terms of aboveground NPP only (Connor and Cherry 1993).

### **Developing the Ranking System**

A literature and online search were conducted to find studies that have quantified the rate of NPP for each of the habitats of interest. The search was initially focused on studies conducted within Texas and/or the Gulf of Mexico. However, if local studies were not found, national and/or international study examples were used. As NPP rates can vary even within a specified habitat type, multiple studies were consulted (~2-4 studies per habitat type were collected where available) and a composite average NPP per habitat type was calculated (Table 7-10).

Each composite average NPP per habitat type was subsequently compared across the habitats of interest to determine and categorize a habitat's NPP rate into a low, moderate, and high ranking (Table 7-10).

Table 7-10: Average Annual Net Primary Productivity Rates and Ranking by Habitat Type\*

Average Appuel Net Primery

Habitat Type	Productivity Rate (lbs. acre/year)	Habitat Ranking
Coastal freshwater marshes	17,840	High
Saltwater marshes	26,784	High
Mangroves	23,560	High
Coastal prairies	7,083	Moderate
Coastal bottomland forests	13,933	High
Seagrasses	19,214	High
Beaches and dunes (unvegetated)	6,491	Moderate
Dunes (vegetated)	1,963	Moderate
Oyster reefs	N/A	Null/Zero
Rookery Islands	No data available	Null/Zero

<sup>\*</sup>Composite average NPP rates were calculated from collected studies. See Attachment B, Table 7-17 detailing the comprehensive list of studies consulted. See Attachment C for habitat descriptions discussing the research studies consulted and additional rationale for habitat ranking (specifically for oyster reefs).



Ranking System

Null/No data - Score = 0

**Low** – Annual NPP rate is low: <1,000 lbs. ac/yr (Score = 0.5)

Moderate - Annual NPP rate is moderate: 1,000 - 10,000 lbs. ac/yr (Score = 1)

**High** – Annual NPP rate is high: >10,000 lbs. ac/yr (Score = 1.5)

# **Cultural Services**

Cultural services are the non-material benefits obtained from an ecosystem through recreation, ecotourism, spiritual, and aesthetic value. For the purposes of this scoring tool, the cultural services of **ecotourism** and **recreation** will be described, as they can be more easily interpreted by researching numbers of visitors to a site/year, the utility of a particular area for both ecotourism and recreation, and the economic value brought to coastal Texas by such habitats.

The region hosts approximately 367 and 3,300 miles of respective Gulf and bay/estuarine shoreline, which comprise many different habitats and support highly desirable cultural services. Often, ecotourism and recreational activities overlap. For the purposes of this tool, ecotourism includes bird watching and paddling/kayaking, whereas recreation includes recreational fishing, hunting, snorkeling/diving, swimming, and camping.

#### **Ecotourism**

Ecotourism is tourism directed towards natural environments and is defined as "responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education" (TIES 2019). Coastal Texas supports many types of ecotourism, with the highest valued and most popular being bird watching and paddling/kayaking. Since there are two ecotourism activities noted as important cultural services offered in coastal Texas, each activity, and the habitats that are supported, are described in more detail below.

According to the Texas Parks and Wildlife Department (TPWD) and Texas Aquatic Science, tourism is the third largest sector in coastal Texas and is estimated to provide \$5.4 billion annually in economic activity (Rosen 2013). TPWD suggests that coastal Texas is the topranked birding site in the world due to the extent of fresh and saltwater wetland habitat and rookery islands which hosts more than 600 migratory and resident bird and waterfowl species year-round (Redwine 1997). The completion of the \$1.5 million Great Texas Coastal Birding Trail offers an expansive 500 miles of routes and more than 200 sites from Beaumont to Brownsville, Texas. The coastal trail meanders through coastal bottomland forests, coastal prairie grasslands, coastal fresh and saltwater marshes, and rookery islands. The Central Flyway of North America includes all of coastal Texas as a critical stopover on migratory routes offering birders around the globe a chance to see migrating species in addition to endangered species such as the whooping crane which winters in the Aransas National Wildlife Refuge. Other documented species include the snow goose, egrets, herons, gulls, turns, and ibises that nest in dense colonies and are found in great abundances along the Texas Coast. Between April and May is when the birding season is at its peak in coastal Texas and brings a substantial economic impact each year. Numerous threats such as erosion, sea level rise, invasive and non-native species, human disturbance, and feral predators have impacted the regions rookery islands and nesting areas, which has led to increased



restoration and protection measures to ensure suitable and healthy ecosystems for bird and waterfowl species.

Additionally, paddling and kayaking comprise another key ecotourism activity that draws many residents and visitors to coastal Texas. Popular coastal paddling trails meander through coastal bottomland forests, such as the Columbia Bottomlands, via coastal rivers that flow into numerous bays within the Gulf. According to TPWD, seagrass beds of Christmas Bay at the western end of the Galveston Bay complex and black mangrove estuaries in the Lighthouse Lakes (Port Aransas) region provide ample opportunities for wildlife viewing. The Armand Bayou Paddling Trail and Coastal Preserve offers a glimpse into the increasingly rare coastal prairie ecosystem. Several other popular and interconnected trails highlight the region's coastal saltwater marshes and the infamous birding opportunities that are available.

# Developing the Ranking System

A literature review was conducted to determine which of the aforementioned ecotourism activities support the target habitats. A ranking system of low, moderate, and high was used to guide project proponents in determining the score of the habitats and activities that may align with proposed project site locations. Habitats that score low do not support either of the ecotourism activities. A moderate score is granted when only one ecotourism activity is supported, and a high score is given if both ecotourism activities will occur within the site location and habitats supported for proposed projects.

A caveat to this scoring method includes the fact that the list of habitats and cultural services provided in Table 7-11 is a list of the *potential* activities that the target habitats may provide, and a site specific determination will be necessary for project proponents to decipher in their application process.

Table 7-11: Habitats Providing Ecotourism Services in Coastal Texas and Habitat Ranking

Habitat Type	<b>Ecotourism Activity Supported</b>	<b>Habitat Ranking</b>				
Coastal freshwater marshes	Bird watching	Moderate				
Saltwater marshes	Bird watching, Paddling/kayaking	High				
Mangroves	Paddling/kayaking	Moderate				
Coastal prairie	Bird watching, Paddling/kayaking	High				
Coastal bottomland forests	Bird watching, Paddling/kayaking	High				
Seagrass beds	Paddling/kayaking	Moderate				
Beaches and dunes	Bird watching	Moderate				
Oyster reefs	None	Low				
Rookery Islands	Bird watching Paddling/kayaking	High				

# Ranking System

**Low –** Neither ecotourism activities supported (Score = 0)



**Moderate** – One ecotourism activity supported (Score = 0.5) **High** – Both ecotourism activities supported (Score = 1)

#### Recreation

Outdoor recreation is an activity done for enjoyment or pleasure. Coastal Texas habitats offer a suite of recreational activities that support the local and state economy. It is estimated that conventional Texas outdoor recreational activities generate over \$11 billion dollars annually (US BEA 2020). Recreational fishing, hunting, hiking, snorkeling/diving, camping, and swimming are the cultural services that comprise the highest valued and most popular activities on the Texas coast while utilizing most of the target habitats.

Each of the recreational activities highlighted for this scoring tool are often supported by a diversity of habitats (e.g., hiking trails may meander through numerous habitats in one trail). Thus, for the purposes of clarity and for the ease of the project proponent, recreational activities are discussed in more detail below including the various habitats that they may support. Project proponents may have a better sense as to the recreational use and activity types at a particular project site, or in adjacent areas, and may be able to provide additional information in funding applications.

#### Recreational Fishing

While the recreational value of fishing is more difficult and less precise to valuate than the highly regulated commercial fishing industry, it is estimated that saltwater recreational fishing in Texas generates \$2 billion annually (Costanza et al. 1989; Rosen 2013). The shallow, fertile bays and estuaries, fed by freshwater inflows, create bottomland forest and coastal wetlands that are home to 95% of recreational and commercially important fish species (at some or all of their life history) within the Gulf of Mexico (Cook 2002). The most common fishery species in all major Texas bays include flounder, sheepshead, spotted seatrout, and red and black drum (Texas Sea Grant). Spotted seatrout and red drum are known to frequent seagrass beds where they predate on juvenile fish, shrimp, and crab species. Oyster reefs are also known to enhance recreational fishing and diving by attracting fish, increasing both the number of fish and biodiversity of the area.

# **Hunting**

Hunting is another culturally and economically important ecosystem service that coastal habitats offer. In 2019, the state of Texas supplied 1,589,078 resident hunting licenses, tags, permits, and stamps equating to a gross cost of \$46,922,156 (USFWS 2019). Coastal bottomland hardwood forests are highly diverse and critical ecosystems that provide ample hunting opportunities. The Columbia bottomlands, coastal prairies, and coastal wetlands along the coast of Texas are critical stopover points for many bird and waterfowl species, a valuable economic resource for avid hunters. The most commonly hunted species within the aforementioned coastal habitats include waterfowl, bird species, feral hogs, small mammals, and alligators.

#### **Hiking**

Hiking is a versatile and popular activity that is common throughout coastal Texas ecosystems. The Columbia Bottomlands provides additional recreational opportunities with a suite of parks and hiking trails that support the local economy and provide cultural services to residents and visitors annually (Blackburn et al. 2014). Nature trails are also prevalent in



Habitat Banking

coastal wetlands where bird watching typically occurs. Further, beaches and dunes offer a variety of hiking trails and wildlife viewing opportunities in coastal Texas.

### Snorkeling/Diving

Snorkeling and diving are referenced in the literature as providing recreational activities for local residents and visitors to witness the diversity of marine organisms that inhabit or visit subtidal oyster reefs and seagrass beds (AECOM 2018).

### **Camping and Swimming**

Beaches and offshore islands host popular camp sites for local residents and out of state travelers, in addition to areas for swimming.

# Developing the Ranking System

A literature review was conducted to determine what the most common recreational activities that occur in coastal Texas and support the target habitats. A ranking system of low, moderate, and high was used to guide project proponents in determining the score of the habitats and activities that may align with proposed project site locations. Habitats that score low do not support the outlined recreational activities listed. A moderate score is granted when only one recreational activity is supported, and a high score is given if two or more recreational activities occur at a site location based on the habitats supported.

A caveat to this scoring method includes the fact that the list of habitats and recreational cultural services provided in Table 7-12 is a list of the *potential* activities that the target habitats may provide, and a site specific determination will be necessary for project proponents to decipher in their application process.

Table 7-12: Habitats Providing Recreational Services in Coastal Texas and Ranking by Habitat Type

Poercational Activity Supported

Habitat Type	Recreational Activity Supported	Habitat Ranking
Coastal freshwater marshes	Hunting	Moderate
Saltwater marshes	Recreational Fishing, Hunting	High
Mangroves	-	Low
Coastal prairie	Hunting	Moderate
Coastal bottomland forests	Hunting, Hiking	High
Seagrass beds	Recreational Fishing, Snorkeling/Diving	High
Beaches and dunes	Hiking, Camping, Swimming	High
Oyster reefs	Recreational Fishing, Snorkeling/Diving	High
Rookery Islands	-	Low

Habitat Type



# Ranking System

Low – No recreational activities supported (Score = 0)
 Moderate – One recreational activity supported (Score = 0.5)
 High – Two or more recreational activities supported (Score = 1)

# **Provisioning Services**

Provisioning services are products derived directly from an ecosystem and may include resources like food, timber, and water. For the purposes of this scoring tool, several key provisioning services and supporting habitats are considered that generate high economic importance and value in coastal Texas, like commercial fisheries, cattle grazing and ranching, and timber harvest.

Commercial fisheries are an important means of food production and are critical ecological and economic components within coastal Texas ecosystems, the local economy, and for local communities. Coastal Texas habitats that enhance commercial fisheries consist of coastal wetlands (freshwater and saltwater marshes/wetlands), mangroves, seagrass beds, and oyster reefs. Coastal bays and estuaries are a broad classification of saltwater coastal wetlands and may encompass mangroves, seagrass beds, and oyster reefs; specific habitat associations are described where detailed information is available.

Other habitats that yield provisioning services within coastal Texas include coastal prairies and coastal bottomland hardwood forests and are discussed at a higher level within this document. These regions have a much smaller extent in coastal Texas but support the local economic system. Coastal prairies are highly impacted ecosystems within coastal Texas and have largely been converted to agricultural fields. Remaining coastal prairie systems are more fragmented within the region and have either been turned into conservation or restoration areas, or support cattle grazing – the largest economic sector in Texas (Texas Department of Agriculture 2021). Coastal bottomland hardwood forests are also under increasing threats from overharvesting of ecological services, agriculture, and urban expansion (Blackburn et al. 2014). The two major bottomland forests in coastal Texas include the Columbia Bottomlands and Trinity River Bottomlands, which are still used for timber harvest.

The remaining habitat types that do not support the life cycles of economically important fishery species or produce other provisioning services (cattle and timber) include beaches/dunes and rookery islands. These habitats are not discussed within the ranking system in further detail, but rather are included as a caveat for future research and implications.

#### **Commercial Fishing**

The most relevant provisioning service provided by Texas coastal habitats is the food obtained from commercial fisheries. Various coastal habitats support and/or enhance essential local fisheries by providing important nursery grounds for juvenile fish (e.g., wetlands) or foraging grounds for adult fish (e.g., seagrass beds and mangroves) or include the habitats themselves which directly support a fishery (e.g., oyster reefs). Specific habitat associations are indicated per fishery where information is available. Habitats are explained in more detail below, including the roles they play in supporting commercial Texas and Gulf of Mexico fisheries. Table 7-13 illustrates the top commercial fishery species for Texas, the habitats that support each species, and the revenue and pounds landed from 2015-2019.



The top ten fisheries for Texas from 2015 to 2019 were obtained from the National Marine Fisheries Service <u>Annual Commercial Landing Statistics</u> database. The database provides information regarding the annual pounds landed and the dollar values generated by each species. The habitats that support fisheries or include a fishery themselves were then further researched to understand how they support the top commercial fisheries within coastal Texas (Table 7-13).

**Table 7-13: Top Commercial Fishery Landings in Texas** 

Fishery Supported	Habitat Type Utilized	Revenue (in millions of dollars) from 2015-19	Pounds Landed (in millions) from 2015-19
Shrimp species: Northern brown shrimp (Farfantepenaeus aztecus), Northern white shrimp (Litopenaeus setiferus), and Northern pink shrimp (Pandalus borealis)	Coastal wetlands, seagrass beds, mangroves, oyster reefs	\$816.75M	346.7M lbs
Eastern oyster (Crassostrea virginica)	Oyster reefs	\$103.3M	17.4M lbs
Red snapper (Lutjanus campechanus)	Seagrass beds, and mangroves (Wells et al. 2008)	\$53.2M	11.7M lbs
Blue crab (Callinectes sapidus)	Coastal wetlands, oyster reefs, seagrass beds	\$28.2M	21.1M lbs
Black drum (Pogonias cromis)	Coastal bays and estuaries, mangroves, oyster reefs	\$11M	9.1M lbs
Yellowedge grouper (Epinephelus flavolimbatus)	Coastal bays and estuaries, muddy substrates (sand-shell)	\$3.86M	856,386 lbs
Atlantic croaker (Micropogonias undulatus)	Coastal wetlands (Whitaker 2005), seagrass beds, and oyster reefs (ASMFC 2005)	\$2.6M	259,409 lbs

#### Coastal Wetlands

Coastal wetlands provide direct provisioning services for fishery species through habitat and nursey support (Blackburn et al. 2014). Fishery species rely on coastal wetlands for shelter, protection, reproduction, rearing of young, and foraging grounds at all or some stages in their life history. Studies suggest that the availability of suitable wetland habitat is linked to the enhanced growth, survival, and reproduction of key fishery species (Engle 2011). Many studies conclude that population density is a straightforward metric to assess the importance of coastal wetland habitats for fisheries (Blackburn et al. 2014). Coastal wetlands within the Gulf of Mexico have been detected to support large quantities of brown shrimp, white shrimp, and blue crabs (Blackburn et al. 2014). Minello et al. 2008 estimated that a marsh complex could support 19,382 brown shrimp per hectare, 17,406 white shrimp per hectare, and 16,726 blue crabs per hectare, which far exceed values observed in the open water of Galveston Bay.



### **Mangroves**

Mangroves are structurally diverse and complex habitats that support high biodiversity through food availability, refuge, and cooler water with high oxygen content when compared to adjacent areas (IUCN 2017). Mangroves are generally home to juvenile fish and shrimp fishery species with enhanced protection and ample food supply. Juveniles are typically found in mangroves prior to venturing out into open water habitats where they replenish oceanic fish stock and increase high-value offshore commercial fishery yields. Mangroves support a wide variety of marine organisms including crabs, shellfish, oysters, fish, and other invertebrates (IUCN 2017).

### Seagrass Beds

Seagrass beds are one of the most highly productive ecosystems in the world (Duarte et al. 2004). They, like mangroves, offer an array of benefits to commercially important species which may include some, or all of the following: vital habitat to complete certain life cycles, nursery support for the development of larval and juvenile stages, enriched foraging grounds, and refuge from predation (Jackson et al. 2001). Additionally, seagrass beds provide indirect, beneficial services for important fishery species by incorporating organic matter into coastal nutrient cycles thereby supporting offshore fishery productivity (Jackson et al. 2001). Shrimp and blue crabs are also known to be highly dependent on seagrass beds as a means of survival, growth, and reproduction along the Gulf of Mexico seagrass beds.

As of a 2013 study, 80% of remnant Texas seagrass beds can be found in the Laguna Madre, which is protected from development by mainland ranches and Padre Island National Seashore (Rosen 2013).

#### **Oyster Reefs**

Oyster reefs are an important habitat type within bays and estuaries along the Texas coast. Oyster reefs support a multimillion-dollar industry of consumer goods each year. However, it is estimated that over 40% of Texas oyster reefs have been lost over the last few decades to overharvesting and degradation (Zu Ermgassen et al. 2012). The value of oysters originating from pristine reefs far exceeds those harvested from degraded reefs in both quality and quantity (Grabowski et al. 2012). This has paved the way for numerous, large-scale oyster restoration projects in Texas to help bolster the ecological and economic benefits oyster reefs provide to surrounding communities.

Oysters contribute to improved water quality as filter feeders and nutrient cyclers, benefitting adjacent habitat quality and important fishery species assemblages. In addition to improving habitat quality, oyster reefs offer ecosystem structure for commercially and/or recreationally important species including shrimp, blue crab, and several game fish species. Juvenile fishery species often recruit to oyster reefs for food, shelter, and/or protection from predators, ultimately benefitting the production and resiliency of fisheries within the Gulf of Mexico (Grabowski et al. 2012).

# **Grazing and Ranchland**

#### Coastal prairies

In addition to commercial fisheries, coastal prairies provide provisioning services within coastal Texas and serve as key grazing and ranching land for cattle. Coastal prairies used to surround bays and estuaries on the Texas coast, covering ~6.5 million acres, but now only occupy 65,000 acres (1% of historical acreage) (Baldwin et al. 2007). Coastal prairies are often



used to raise cattle and would account for approximately \$6.3 million dollars in coastal Texas when deducing from statewide totals and acreages of coastal prairies still intact. The Texas Department of Agriculture states that as of 2017, Texas led the nation in number of farms and ranches, covering a total of 127 million acres and selling \$24.9 billion in agricultural products (\$12.3 billion of which is from cattle, the largest market commodity in Texas).

#### **Timber Harvest**

#### **Bottomland forests**

Coastal bottomland hardwood forests, largely found in East Texas and Galveston Bay, are one of the most diverse ecosystems in Texas (McWilliams and Lord 1988). This ecosystem type has largely been impacted by swamp draining and logging practices. In general, the southeast has experienced degradation and loss of bottomland forests from previous land-use and timber harvesting practices, which has spurred recent restoration and conservation initiatives within these vital habitats to conditions that are suitable for both ecological and economically valuable practices.

Along the Texas coast, there are two significant bottomland forests – one of which is the Columbia Bottomlands (250 sq. miles), fed by the Brazos, San Bernard, and Colorado Rivers that drain into the Gulf of Mexico; the second is the Trinity River Bottomlands where the Trinity River drains into Galveston Bay.

#### **Developing the Ranking System**

For provisioning service, we elected to use a binary scoring system (yes/no) to encompass the distinct services that are provided within the target habitats of coastal Texas. Grazing and Ranchland and Timber Harvest services were associated with only one habitat type, and thus we were unable to use the ranking system utilized in earlier sections above (Table 7-14).

Table 7-14: Provisioning Services Provided and Ranking by Habitat Type

Habitat Type	Provisioning Service Provided	Habitat Ranking
Coastal freshwater wetlands	Commercial fishing	Yes
Coastal saltwater wetlands/marshes	Commercial fishing	Yes
Mangroves	Commercial fishing	Yes
Coastal prairie	Grazing and ranchland	Yes
Coastal bottomland forests	Timber harvest	Yes
Seagrass beds	Commercial fishing	Yes
Beaches and dunes	None	No
Oyster reefs	Commercial fishing	Yes
Rookery Islands	None	No

#### Ranking System

Yes = score 1 No = score 0



# **Additional Ecosystem Services**

Additional ecosystem services project proponents can consider including in grant applications, but which are not scored using the ranking system are listed below. In addition to the ecosystem services discussed previously, these services could be discussed qualitatively in a hazard mitigation funding grant application.

# **Regulating Services**

# Water Quality Improvements (Water filtration/removal of suspended sediment)

- **Coastal wetlands** improve water quality by filtering out excess nutrients, sediment, pollutants, and pathogens from overland flows before they enter open water (TCX 2020).
- **Coastal prairies** improve water quality by absorbing excess nitrogen and phosphorus. This improves water quality for both surface and groundwater supply (TCX 2020).
- Coastal bottomland forests improve water quality by filtering out excess nutrients and pollutants (TCX 2020).
- Oyster reefs: As filter feeders, oyster can filter large quantities of water removing chlorophyll, sediment, pathogens, and nutrients from the water column. This in turn increases water clarity and light penetration into shallow waters which benefits submerged aquatic vegetation and other aquatic species reliant on these vegetation communities (Blackburn et al. 2014). Numerous in situ water conditions and factors, together with oyster size, play a role in determining the volume of water oysters can filter and their efficacy of filtration (Zu Ermgassen 2012).

# Nutrient Control and Regulation (Maintenance of nutrients within acceptable bounds)

- **Coastal wetlands** are very effective at filtering out excess nitrogen and phosphorus present in coastal waters (Blackburn et al, 2014).
- **Coastal prairies:** Coastal prairies are sinks for inorganic nitrogen and phosphorus and help regulate water quality by capturing and controlling the release of nutrients (Blackburn et al, 2014).
- Coastal bottomland forests filter out excess nutrients such as nitrogen through the process of denitrification (Blackburn et al. 2014).
- Oyster reefs: Due to the oysters' filter feeding abilities, they are able to filter out nitrogen present in coastal waters reducing the potential of over-enrichment and eutrophication events from occurring, a frequent concern in coastal zones (Blackburn et al. 2014).
   Oysters remove planktonic nitrogen from the water assimilating approximately 50% of particulate organic nitrogen into their tissue and shell (Pollack 2013). The remaining 50% is excreted as 'biodeposits' and is either buried in sediment or undergoes denitrification. Both processes result in nitrogen being removed from the water column (Pollack 2013).

#### **Biological Regulation (Species interactions)**

• **Coastal prairie** habitats support a large diversity of pollinator populations that include bees, birds, bats, butterflies, and beetles. Pollinators are essential in maintaining the nation's food supply and natural habitats (TCX 2020).



# **Supporting Services**

# Nutrient Cycling (Storage, processing, and acquisition of nutrients within the biosphere)

- Coastal wetlands play a role in nutrient cycling (Brander et al. 2006).
- Mangroves facilitate the exchange of dissolved and particulate organic matter between the forest environment and adjacent coastal waters (Singh et al. 2005; AECOM 2018).
- Coastal prairies wetlands act as nutrient sinks capturing inorganic nitrogen and phosphorus coming from upland sources. They capture and control the release of these nutrients and help regulate water quality further downstream (Blackburn et al. 2014).
- **Seagrass** meadows capture sand, dirt, and silt particles from runoff from land, while the leaves absorb nutrients from the water and the soil (AECOM 2018).

# **Aquifer Recharge**

- Coastal wetlands have high infiltration rates and replenish groundwater supply (Brander et al. 2006).
- Coastal prairies replenish groundwater supply (Blackburn et al. 2014).
  - **Coastal bottomland forests** have high water infiltration rates and can replenish groundwater during heavy rain and flood events (TCX 2020).

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# **Attachment A**

UM					lab	ole 7-15	Project Type Benefit to Ecos	ystem	Services Matrix																						
									Benefits to E	cosyst	em Service Catego	ories	_																		
v														Co-benefits (Total Score 11)																	
	TEST SCORE RUN EXAMPLE				Regulating	Service	s relevant to hazard mitigation	funding	g (Total Score = 16)					Regulatin (Total sc				Supporting Se	ervices	(Total S	core = 6.	.5)					Services ore = 2)		Provisi Service: Score	(Total	
	Project Name	Project Type	Is project considered a pre- or post- hazard mitigation' project (targeting hazards such as flood mitigation, coastal storm surge protection, erosion control, shoreline stabilization)?  (YES or NO)	(YES = 2;	Is the proposed project located in a vulnerable coastal zone as assessed by the 'ecological vulnerability index' or 'risk score'? (YES or NO)	Score (YES = 2; NO = 0)		Score (YES = 2; NO = 0)	Storm Surge Protection/Flooding Protection	Score	Erosion Control/Shoreline Stabilization	Score	Total Regulating Services Score	ng Carbon Species Listed Critical Primary					Ecotouris m	Score F	Fisheries/ Timber/ ecreation Score Grazing Sco			Score	Total Co- benefits score (11)						
	Portland Living Shoreline	Shoreline stabilization using a rock breakwater and enhancing/creating wetlands (planting wetland plants)	YES	2	YES	2	YES	2	MEDIUM	3	HIGH	5		MEDIUM	1	HIGH	1.5	MEDIUM	1 ME	DIUM 1	NO	0	HIGH	1.5	LOW	0	LOW	0	yes	1	
	Galveston Island West of Seawall to 8 Mile Road Beach Nourishment	Shoreline stabilization by creating a feeder beach (beach nourishment)	YES	2	YES	2	YES	2	HIGH	5	MEDIUM	3		LOW	0	MEDIUM	1	LOW (	0.5 L	ow o.	5 NO	0	LOW	0.5	нібн	1	HIGH	1	No	0	

# **Attachment B**

# Table 7-16. Collected Studies of Carbon Sequestration Rates Per Habitat Type

Reported Annual Carbon Sequestration Rate in literature (g C/m²/year or metric tons (Mt)

Annual Carbon Sequestration Rate

Habitat Type	C/ha /year) *	(lbs. C/acre/year)	Reference	Notes
Coastal freshwater marshes				
	340-900	3,033 – 8,028 Average rate: 5,531	Krauss et al. 2018	Carbon mass balance of tidal freshwater marshes over an 11-year period on 2 tidal rivers on U.S. south east coast
	7-337	62 – 3,006 Average rate: 1,533	Krauss et al. 2018	Soil carbon burial rates of tidal freshwater marshes over an 11-year period on 2 tidal rivers on U.S. south east coast
Coastal freshwater marshes: No average value calculated as there is only one data point for each variable				
Saltwater marshes				
		2,319	Engel 2011	Meta-analysis of wetland carbon sequestration rates conducted along the Gulf of Mexico coast
		508	Chmura et al. 2003	Global average carbon sequestration rates
		8,465	Choi et al. 2001	Low marsh – closest to open water (Florida)
		5,307	Choi et al. 2001	Middle marsh (Florida)
		2,168	Choi et al. 2001	High marsh – farthest inland (Florida)
		357	Loomis et al. 2010	Coastal marsh – conservation estimate, Georgia
Saltwater marshes: Average from above studies (as reported in Blackburn et al. 2014)	117	3,187		
Mangroves				
	226	2,016	McLeod et al. 2011	Global Meta-analysis: average carbon burial rate across 34 mangrove sites
	5.27 Mt C/ha/year	4,702	Salem and Mercer 2012	Global Meta-analysis considering mangrove carbon sequestration rates in 18 countries

# Reported Annual Carbon Sequestration Rate in literature (g C/m²/year or metric tons (Mt)

Annual Carbon
Sequestration Rate
(lbs. C/acre/year) Reference

Habitat Type	(g C/m²/year or metric tons (Mt) C/ha /year) *	Sequestration Rate (lbs. C/acre/year)	Reference	Notes
Mangroves: Average from above studies		3,359		
Coastal prairies				
	268	2,386	Suyker and Verma 2001	Tallgrass, Oklahoma (monitoring conducted in 1996 -1998)
	80	712	Dugas et al. 1998	Tallgrass, Texas
	70	623	Sim and Bradford 2001	Mixed grass, Southern Plains (Bowen ratio/energy balance used)
	48	428	Potter et al. 1999	Restored grassland, Texas. Compared pristine prairie versus degraded agricultural soil.
Coastal prairies: Average from all studies (as reported in Blackburn et al. 2014)	117	1,037		
Coastal bottomland forests				
		2 tons C/acre/year	Jenkins et al. 2009	Mississippi Alluvial Valley
		1,842 lbs. C/acre/year	USDA 1992 (as referenced in Blackburn et al. 2014)	Forest type estimates (South Central Region)
		2,330 lbs. C/acre/year 2.4 tons C/acre/year	Simpson et al. 2013	Forest type estimates Ecoregion estimates (Texas State-wide Assessment of Forest Ecosystem Service)
Coastal bottomland forests: Average from all studies (as reported in Blackburn et al. 2014)		1.8 tons C/acre/year Or 4,032 Ibs/acre/year		
Seagrasses	138	1,231	McLeod et al. 2011	Global Meta-analysis: average carbon burial rate across 123 seagrass bed sites

Habitat Type	Reported Annual Carbon Sequestration Rate in literature (g C/m²/year or metric tons (Mt) C/ha /year) *	Annual Carbon Sequestration Rate (lbs. C/acre/year)	Reference	Notes
	1-66.5	Range: 9 – 593 Average: 292	Lavery et al. 2013	Estimates of Australian seagrass carbon accumulation rates
	6-175	Range: 54 – 1561 Average: 754	Lavery et al. 2013	Estimates of Posidonia oceanica seagrass carbon accumulation rates
	282	2,515	Hughes 2015	Estimate of <i>Zostera marina</i> seagrass carbon sequestration rates, Echo Bay, WA
Seagrass: average from all studies		1,198		
Beaches	N/A			
Dunes (vegetated)**				
	58 to 73 Average rate: 60	517 – 651 Average rate: 535 (as quoted in the study)	Jones et al. 2008	Carbon sequestration rates for vegetated sand dunes on the British west coast, United Kingdom (based on dry dune grasslands and wet dune slack habitats).
Oyster reefs**				
	Carbon sinks: subtidal sandflat reefs (1.0 Mt C/ha/year) saltmarsh-fringing oyster reefs (1.3 Mt C/ha/year) Carbon sources: Intertidal sandflat reefs (-7.1 Mt C/ha/year)	Carbon sinks: subtidal sandflat reefs (892 lbs C/ ac/yr) saltmarsh-fringing oyster reefs (1,160 lbs C/ ac/yr) Carbon sources: Intertidal sandflat reefs (-6,300 lbs C/ ac/yr)	Fodrie et al. 2017	Considered carbon sequestration potential of 19 constructed experimental oyster reefs and three natural reefs in Rachel Carson National Estuarine Research Reserve, NC
 Rookery Islands	No data available			

<sup>\*</sup>Conversions used: 1g C/m²/yr= 8.92 lbs./acre/yr and
1 metric ton C/hectare/yr = 892.18 lbs./acre/yr

<sup>\*\*</sup>Only one relevant study found for habitat type

Table 7-17. Collected Studies of Net Primary Productivity Rates per Habitat Type

Habitat Type	Net Primary Productivity Rate (g C m²/year)*	Net Primary Productivity Rate (g C m²/year)*	Net Primary Productivity (lbs. C /acre/year)	Reference	Notes
Coastal freshwater marshes					
		1,000-3,000 g m <sup>2</sup> /year	8,920 – 26,760	Mitsch and Gosselink 1993	Range is derived from multiple studies depicting annual production rates of various freshwater wetland plant species (above or belowground NNP not specified)
Coastal freshwater marshes: Average NNP rate			17,840		
Saltwater marshes					
		750-2,895 g m²/year	6,690 – 25, 823 Average rate: 16,257	Kirby and Gosselink 1976; White et al. 1978; Hopkinson et al. 1980 (as referenced in Mitsch and Gosselink 1993)	Louisiana marshes (Aboveground NPP for <i>Spartina alterniflora:</i> height form of plants - all tall)
		130-700 g m²/year	1,160 – 6,244 Average rate: 3,702	Kruczynski et al. 1978 (as referenced in Mitsch and Gosselink 1993)	Florida marshes: (Aboveground NPP for Spartina alterniflora: height form of plants range from short to tall)
		1089-1964 g m²/year	9,714 – 17,519 Average rate: 13,617	De la Cruz 1974 (as referenced in Mitsch and Gosselink 1993)	Mississippi (Aboveground NPP for Spartina alterniflora: height form of plants range from short to tall)
		8,247 g m²/year	73,563	Stout et al. 1978 (as referenced in Mitsch and Gosselink 1993)	Alabama marshes: (Above- and belowground NPP for Spartina alterniflora: height form of plants not specified)

Habitat Type	Net Primary Productivity Rate (g C m²/year)*	Net Primary Productivity Rate (g C m²/year)*	Net Primary Productivity (lbs. C /acre/year)	Reference	Notes
Saltwater marshes: Average NNP rate			26,784		
Mangroves					
		1100-5400	9,812-48,168 Average rate: 28,990	Mitsch and Gosselink 1993	Range derived from multiple studies along the coast of Florida and Puerto Rico for fringe and basin mangroves.
		1,607 g m²/year for a fringe mangrove to 2.458 g m²/year for a riverine mangrove	14,334 lbs. /ac/yr for a fringe mangrove— 21,925 lbs. /ac/yr for a riverine mangrove Average rate: 18,129	Day et al. 1987 (as referenced in Mitsch and Gosselink 1993)	Aboveground NPP in a fringe and riverine mangrove in Mexico (above or belowground NNP not specified)
Mangroves: Average NNP rate			23,560		
Coastal prairies					
		462 g/m²in an unburned grassland plot and 624 g/m² in a burned grassland plot. 1,264 g/m² in a woodland part of the coastal prairie	4,121 lbs./ac in an unburned grassland plot 5,566 lbs./ac in a burned grassland plot. 11,275 lbs./ac in a woodland part of the coastal prairie	Harcombe et al. 1993	This study calculates above-ground NPP in a burned versus unburned coastal prairie in Texas.  ANPP is measured over a 2-yr growing season.  Woodland was comprised of a monospecific stand of invasive Sapium sebiferum (NPP rate not given per year)
		623 and 628 g m²/year	5,557 and 5,602	Irving et al. 1980	Aboveground NPP in 2 prairies that had been burned and hayed annually for 65 years, Great Prairie Region, AR
		1,131 g m²/year	10,089	Irving et al. 1980	Aboveground NPP in a prairie protected for 16 years, Great Prairie Region, AR

Habitat Type	Net Primary Productivity Rate (g C m²/year)*	Net Primary Productivity Rate (g C m²/year)*	Net Primary Productivity (lbs. C /acre/year)	Reference	Notes
Coastal Prairies: Average NNP rate calculated from last two examples as they are in the same units.			7,083		
Coastal bottomland forests					
		1,198g /m²/yr to 2,926 g /m²/yr	10,686 – 26,100 Average rate: 18,393	Koontz et al. 2016	Considering above ground net primary productivity in a riparian wetland following restoration of hydrology, Memphis TN
		1,374	12,256	Connor and Daly 1976 as referenced in Mitsch and Gosselink 1993	Louisiana bottomland forests: aboveground NPP (litter fall + stem growth)
		700 to almost 1800 g /m²/yr	6,244 – 16,056 Average rate: 11,150	Connor and Cherry 2013	Above ground NPP of bottomland hardwood forests
Coastal bottomland forests: Average NNP rate			13,933		
Seagrasses					
<u>-cag</u> .uccc		1,012	9,027	Duarte and Chiscano 1999	Considering above and below ground NPP of 30 seagrass species
		1,200 – 1,700	10,704 – 15,164 Average rate: 12,934	Koch and Madden 2001	Lagoon in the Bahamas considering annual production rates of seagrass species ( <i>T</i> testudium) aboveground NPP
		~4,000	35,680	Moncrieff et al. 1992	Contributions of seagrass species ( <i>H. wrightti</i> ), epiphytic algae, sand microflora and phytoplankton in seagrass beds to NPP in Mississippi Sound, MS

Habitat Type	Net Primary Productivity Rate (g C m²/year)*	Net Primary Productivity Rate (g C m²/year)*	Net Primary Productivity (lbs. C /acre/year)	Reference	Notes
Seagrasses: Average NNP rate			19,214		
Beaches					
	4-9 gC/ m <sup>2</sup> /yr	8–18	71-161 Average rate: 116	Steele and Baird 1968	NPP of photosynthetic diatoms present in beach sand up to 20-cm deep
	480 g C/m²/yr	960	8,563	Campbell and Bate 1988	Lab incubation and modelling studies of phytoplankton on South African beach
	1.2 – 2.1 g C/m²/day	876-1,533	7,814-13,674 Average rate: 10,744	Heymans and MacLachlan 1996	Lab incubation and modelling studies of phytoplankton on South African beach
Beaches: Average NNP rate			6.491		
Dunes (vegetated)					
		226 to 274	2,016 – 2,444 Average rate: 2,230	Dilustro and Day 1997	Aboveground NPP of 2 dominant grass species Spartina patens and Ammophila breviligulata on Barrier Island, VA. Range listed is determined by age of dune from 6 – 120 year old dunes.
		190	1,695	McLachlan and Brown 2006	Dune plant productivity
Dunes (vegetated): Average NNP rate			1,963		
Oyster reefs					
		N/A			Oyster reefs are filter feeders regulating the primary productivity of photosynthetic phytoplankton
Rookery Islands	No data available  2/vr= 8.92 lbs /acre/vr and 1 g C = 2g Dry weight				

<sup>\*</sup>Conversions used: 1g C/m²/yr= 8.92 lbs./acre/yr and 1 g C = 2g Dry weight

#### **Attachment C**

# Habitat Descriptions for Carbon Sequestration Rates of Texas Coastal Habitats: (See Attachment B, Table 7-16)

#### Coastal freshwater marshes

Coastal freshwater marshes occur along on the upper reaches of river-associated estuaries and are not normally included in 'blue carbon' accounting (Krauss et al. 2018). They include tidal freshwater forested wetlands and brackish (low salinity) marshes. These marshes can support high rates of carbon sequestration despite releasing some carbon back into the atmosphere through methanogenesis (Krauss et al. 2018). A recent study conducted by Krauss et al. 2018 along two rivers on the U.S. Atlantic coast in South Carolina and Georgia, found the carbon mass balance over an 11-year period for coastal freshwater marshes to range from 3,033 – 8,028 lbs. C/acre/year. The mass carbon balance considers inputs from litterfall, woody and herbaceous plant growth, root growth, and surface accumulation minus outputs from surface litter, root decomposition and release of gaseous carbon. Annual soil carbon burial rates ranged from 62 – 3,006 lbs. C/acre/year. From this range annual average soil carbon burial rate was estimated at 1,500 lbs. C/acre/year for coastal freshwater marshes.

#### Saltwater marshes

Coastal wetlands are highly valued for their increased ability to store carbon, sequestering carbon within living biomass, within non-living biomass and in marsh soils (Blackburn et al. 2014). Carbon sequestration rates in saltmarshes can vary considerably but is primarily dependent on flooding frequency and sedimentation rates (Chmura et al. 2013). Estuarine wetlands sequester carbon at a rate 10 times higher than other wetlands due to high sedimentation rates, naturally high soil carbon density, and burial of carbon under sediments due to sea level rise (Bridgham et al. 2006). As saltmarshes vertically accrete, carbon stored in the soils can remain in place for many centuries as new sediment continually accumulates on top of it trapping the carbon in place (Mcleod et al. 2011). Some studies estimate that soil carbon can account for 98% of the total carbon pool (Engle 2011).

The potential for a saltmarsh to store carbon is additionally influenced by anthropogenic activities such as clearing, dredging, and filling. By disturbing wetland sediment and vegetation much of the carbon stored in saltwater marshes is released back into the atmosphere. Releasing carbon stored in soils has the potential to release massive amounts of stored carbon back into the atmosphere (Mcleod et al. 2011).

The average annual carbon sequestration rate of saltwater marshes was estimated at 3,187 lbs. C/acre/year. This composite average was calculated from four studies that estimated carbon sequestration rates of coastal marshes along the Gulf of Mexico, Florida, and Georgia coasts and from an international meta-analysis study (Choi et al. 2001 as referenced in Blackburn et al. 2014; Chmura et al. 2003; Loomis et al. 2010 and Engel 2011).

# **Mangroves**

Mangroves contribute approximately 1 percent of carbon sequestration by the world's forests, however, among coastal habitats they contribute roughly 14 percent of carbon sequestration by the global ocean (Alongi 2014). They are able to store carbon more effectively and

permanently than terrestrial forests, storing up to 5 times more carbon than most other tropical forests around the world (Silori 2011).

Similar to other coastal wetlands, mangroves sequester large amounts of carbon deep within their organic soil layer and entangled root system. Mangrove sediment is characterized by low oxygen conditions, which slows down the decomposition rate of organic matter. This allows significant amounts of carbon to be sequestered in the soil over the long term. For this reason, mangrove sediments contain more carbon than most tropical forests have in both their biomass and soil combined (Silori 2011).

The average carbon sequestration rate for mangroves from two studies was estimated at 3,359 pounds of carbon sequestered per acre per year. The two studies conducted a global meta-analysis of reported rates of sequestration rates from mangroves habitats around the world (Mcleod et al. 2011; Salem and Mercer 2012). Sequestration rates ranged from 18 to 80,700 lbs. C/acre/year (Mcleod et al. 2011; Salem and Mercer 2012)

# **Coastal prairies**

Prairies are able to store large amounts of carbon depending on land management practices and vegetation cover. Carbon is stored in the extensive root system of these grasses, which can extend as far as 15 feet deep, and in the soil underground as plants grow and create new soil (Jones and Donnelly 2004 as referenced in Blackburn et al. 2014). Throughout Texas and the U.S., large tracts of prairie land have been converted to agricultural lands. Recent research has shown that prairies are able to sequester more carbon than agricultural lands which has created an increased incentive to restore agricultural lands back to native prairie grasslands (Blackburn et al. 2014). One of the primary reasons that prairies supply greater carbon to the soil is due to longer carbon residence time. Unlike agricultural lands, prairies do not need to be tilled or experience other major soil disturbances commonly associated with farming practices (Jones and Donnelly, 2004).

The average carbon sequestration rate for prairie grasslands from four studies conducted in Texas or similar habitats in the mid-west was estimated at 1,037 pounds of carbon sequestered per acre per year. The values from the four studies ranged from 712 to 2,386 pounds of carbon per acre per year (Dugas et al., 1998; Potter et al., 1999; Sim and Bradford, 2001; Suyker and Verma, 2001).

#### **Coastal bottomland forests**

Coastal bottomland forests are able to sequester large amounts of carbon every year through natural vegetation growth in their understory vegetation and in their large hardwood trees. Additionally, carbon is also sequestered at high rates through soil formation, and biogeochemical processes within the wetland soils and waters (Blackburn et al. 2014).

Clearing hardwood forests or draining the wetland releases large amounts of carbon dioxide and methane gas into the atmosphere, both potent greenhouse gases, changing the basic function of the wetland to a carbon source instead of a carbon sink. This, however, can be reversed if the original habitat type is restored to its original hydrology and vegetation types (Coastal Wetland Forest Conservation and Use Science Working Group 2005 and Jenkins 2009, as referenced in Blackburn et al. 2014).

Blackburn et al. 2014 estimated that the Texas bottomland forests sequester an average of 1.8 tons of carbon per acre per year (or 4.032 lbs. C/acre/year) based on a review of four studies of similar forest types in Louisiana, the Mississippi Alluvial Valley and Texas forests (values ranged from 0.9 to 2.4 tons of carbon per acre per year). Carbon sequestration rates from Texas forests were estimated based on forest type and their respective carbon sequestration rates. For e.g., carbon sequestration rates were available for oak-gum-cypress forests and elm-ash-cottonwood forests, as Bottomland forests are considered to be comprised 50/50 of both forest types and estimated carbon sequestration rate were derived from those two forest types. (Simpson 2013 as referenced in Blackburn et al. 2014)

# **Seagrasses**

Seagrasses cover less than 0.2% of the ocean floor but are able to sequester up to 10% of the carbon buried in ocean sediment annually (BCI 2019). Carbon is stored in seagrass habitats predominantly in their soils, which have been measured up to 4m deep (~13 ft). Slow decomposition rates in seagrass sediment due to low nutrient concentration and reduced oxygen levels, facilitates high rates of carbon burial in the sediment (Duarte et al. 2011). Per hectare, seagrasses are able to store twice as much carbon as terrestrial forests (BCI 2019). Rate of carbon sequestration, which is variable among seagrass habitats, is dependent on seagrass species present, rate of sedimentation and water depth (Lavery et al. 2013).

Studies estimating the amounts of carbon sequestered once a seagrass meadow is restored, showed that restored seagrasses can sequester large amounts of carbon within a short time following restoration. This differs from mangroves that take some years before sequestration occurs in large amounts (DelVecchia et al. 2014). Greiner et al. 2013 found that restored seagrass beds can accumulate carbon at a rate that is comparable to measured ranges in natural seagrass beds within 12 years of seeding.

The average carbon sequestration rate for seagrasses from three studies was estimated at 1,198 pounds of carbon sequestered per acre per year. The studies considered carbon sequestration rates of Australian seagrass beds and European seagrass beds as well as carbon sequestration rates of seagrass beds from Washington State and a meta-analysis of carbon burial rates of 123 seagrass beds worldwide. The values from the three studies ranged from 9 to 2,515 pounds of carbon per acre per year (McLeod 2011; Lavery et al. 2013; Hughes 2015).

#### **Beaches**

As beaches contain little to no vegetation the carbon sequestration potential of this habitat type is negligible. For this reason, it will not be considered for this habitat type.

#### **Dunes (Vegetated)**

Coastal sand dunes that are vegetated have the potential to sequester carbon. Along the Texas coast vegetated and stable dunes are found on Mustang and North Padre Islands. As rainfall decreases southward along the Texas coast, dunes become less vegetated. In general, sand dunes are stressful and vulnerable habitats, where vegetation is subject to harsh environmental conditions such as drought, low nutrient content, high temperatures, salt spray and sand burial (Jones 2011). For this reason, vegetation cover on sand dunes can be lower and can limit the carbon sequestration potential of this habitat type. There are limited studies estimating carbon sequestration rates of coastal sand dunes. One study found estimated

these rates on coastal sand dunes in the United Kingdom. The average annual carbon sequestration rates were estimated at 535 pounds of carbon per acre per year (Jones et al. 2008).

# Oyster reefs

Similar to estuarine wetlands and seagrass meadows, oyster reefs can persist over long time scales potentially acting as long-term vessels for carbon storage (Fodrie et al. 2017). However, there is still much uncertainty as to the role oyster reefs play in acting as either atmospheric carbon sinks or sources. While oysters can sequester carbon by filtering out particulate plant matter and depositing the resultant particulate organic matter into the reef sediment matrix, oysters also release carbon to the atmosphere during oyster shell synthesis. Fodrie et al. 2017 conducted a study to quantify oyster reef carbon sequestration potential. The study demonstrated that oyster reefs exhibited variable potential to sequester carbon based on reef location. Oyster reefs located in the subtidal zone and those located closer to the vegetated shorelines sequestered more carbon due to higher concentrations of organic-carbon rich sediments, while oyster reefs located on intertidal sandflats released carbon to the atmosphere during the biochemical process of oyster shell synthesis (Fodrie et al. 2017). Due to oyster reefs inconsistent ability to sequester carbon, this habitat type was ranked as 'low' for its carbon sequestration potential.

# **Rookery Islands**

No data available

# Habitat Descriptions for Net Primary Productivity Rates of Texas Coastal Habitats: (See Attachment B, Table 7-17)

#### Coastal freshwater marshes

Coastal freshwater marshes exhibit high levels of primary productivity. Annual productivity rates have been reported between 1000-3000 g m<sup>2</sup>/yr or 8,920 – 26,760 lbs. ac/yr (Odum et al. 1984). This range is derived from multiple studies, and the high variability can be attributed to a lack of standardization of measurement techniques, but real differences are also a result of (Mitsch and Gosselink 1993):

- 1. Genetic differences among plants: Type of plant and its growth habitat e.g. tall perennial grasses are more productive than broad-leaved herbaceous species. (Mitsch and Gosselink 1993).
- 2. Tidal energy: moving and incoming water have shown to stimulate primary productivity (as seen with riparian wetlands and saltmarshes).
- 3. Other factors: soil nutrients, grazing, parasites, and toxins have been shown to limit primary productivity (Mitsch and Gosselink 1993)

#### Saltwater marshes

Saltwater marshes are one of the most productive ecosystems in the world. Primary production rates for saltwater marshes in the southern Coastal Plain of North America have been reported as high as 8,000 g m²/yr or 71,360 lbs. ac/yr. Average NPP rates reported across four studies estimating NPP rates of saltmarshes in Louisiana, Florida, Alabama, and Mississippi was estimated at 26,784 lbs. ac/yr ranging from 1,160-73,563 lbs. ac/yr (Mitsch and Gosselink 1993).

Three primary autotrophs are responsible for the high productivity rates in saltmarshes: marsh grasses, mud algae and phytoplankton in tidal creeks. Additionally, higher productivity rates in the southern coastal plain region are likely due to greater solar energy influx, a longer growing season and nutrient-rich sediments delivered by the rivers of the region (Mitsch and Gosselink 1993).

#### **Mangroves**

Mangroves can be highly productive ecosystems depending on their location. Primary productivity rates in mangrove wetlands show great variability due to the varying hydrodynamics (tides and runoff) and chemical conditions encountered at different sites (Mitsch and Gosselink 1993). Mangrove wetlands can be categorized into four dominant types categorized by location along the coast:

- Fringe mangroves: Are found along protected shorelines and along some canals, rivers, and lagoons
- 2. Riverine mangroves: Are found along edges of coastal rivers and creeks, extending several miles inland
- 3. Basin mangroves: Are found in inland depressions usually behind fringe mangrove wetlands
- 4. Dwarf (scrub) mangroves: Coastal wetlands comprised of stunted and scattered mangrove trees. Growth is restricted most frequently due to poor nutrient availability or due to colder winter temperatures that can restrict mangrove growth along the northern edges of their range (Mitsch and Gosselink 1993).

Research has shown that NPP rates are highest in riverine and fringe mangroves, lower in basin mangroves and lowest in dwarf mangrove wetlands (Brown and Lugo 1982 as referenced in Mitsch and Gosselink 1993). Generally, NPP rates across fringe, riverine and basin mangroves are high and range from 9,812 – 48,186 lbs. ac/yr (Mitsch and Gosselink 1993).

# **Coastal prairies**

Coastal prairie habitats are mainly comprised of grasses together with a diverse array of wildflowers. Areas closer to the coast are dominated by shorter grasses and other vegetation types that are adapted to coastal storms and winds, while areas further inland at higher elevations have taller grasses and shrubs. Prairies are productive ecosystems that support a large variety of wildlife and provide grazing land for cattle (TCX 2020). These grasslands are ideal for cattle grazing as they are drought and fire-tolerant, and do not require maintenance of non-native pastures (TCX 2020).

Average annual NNP rates of three prairie grasslands in Arkansas was estimated at 7,083 lbs. ac/yr. The study assessed three types of prairie grasslands: one protected prairie and two prairies that were burned and hayed annually over a 65-year period (Irving et al. 1980). A second study estimating NPP in a Texas coastal prairie determined an average NNP rate of 4,843 lbs. ac/yr between an unburned versus a burned prairie plot (Harcombe et al. 1993). The burned prairie plot had a slightly higher NPP rate of 5,566 lbs. ac/yr compared to the unburned plot NPP 4,121 lbs. ac/yr.

#### **Coastal bottomland forests**

Coastal bottomland forests, or riparian forests/wetlands, are some of the most productive forests of the temperate zone (Conner and Cherry 2013). Their productivity is directly related to their unique hydrology. Frequency of flooding and inundation, however, play a pivotal role in determining primary productivity rates in this habitat type. Bottomland forests that experience intermittent flooding have higher primary productivity rates than riparian forests that remain flooded all year round (Wharton 1982). Periodic flooding provides a regular water supply, an influx of essential nutrients and allows for oxygenation of the root zone while also 'flushing' away metabolic waste products produced by the root system (Mitsch and Gosselink 1993). Riparian wetlands that are permanently flooded have lower productivity rates due to an accumulation of acidic peat soils, low nutrient levels due to anoxia and have low pH (Wharton 1982).

On average riparian wetlands that have an unaltered annual cycle of wet and dry periods produce aboveground NPP rates of ~8,900 lbs. ac/yr (Mitsch and Gosselink 1993). The average annual NNP rate across three studies estimating NPP rate of riparian wetlands in Tennessee and Louisiana is ~14,000 lbs. ac/yr (Mitsch and Gosselink 1993; Connor and Cherry 2013; Koontz et al. 2016)

#### Seagrasses

Seagrass meadows are considered one of the most productive marine plant communities covering approximately 0.15% of the ocean surface in temperate and tropical zones (Duarte and Chiscano1999; TPW 1999). Despite their small global extent, their net primary productivity contributes ~1% to the global net marine primary productivity (Duarte and Chiscano 1999). NPP rates for seagrass meadows are reported to range between ~9,000-

35,680 lbs. ac/yr (Duarte and Chiscano 1999; Moncrieff et al. 1992; Koch and Madden 2001). Factors affecting seagrass NPP rates include light and nutrient availability, temperature, and biodiversity of seagrass species present. Additionally, the presence of epiphytic algae, benthic microalgae and phytoplankton that reside in and around seagrass meadows further help to contribute to the high productivity rates of these marine ecosystems (Moncrieff et al. 1992; TPWD 1999; Duarte and Chiscano 1999; Plus et al. 2001).

#### **Beaches**

Sandy beaches have little to no vegetation, but they do contain photosynthetic diatoms (phytoplankton) that are present in the sand at depths of up to 20-cm in the lower reaches of the beach at the low water line (Steel and Baird 1968). The constant wave action in this zone, however, limits the NPP rates of these diatoms keeping NPP rates low at 71–161 lbs. ac/yr (Steel and Baird 1968). Recent research has shown that the surf zone of beaches, the region of the beach where approaching waves are breaking, can be extremely productive areas in terms of NPP rates of phytoplankton (Cahoon et al. 2017). Some lab incubation and modelling studies have shown potential NPP rates of certain beach surf zone regions in South Africa to range as high as ~ 7,814-13,674 lbs. ac/yr (Campbell and Bate 1988; Heymans and MacLachlan 1996). Average NPP rate across the three studies was estimated at 6,491 lbs. ac/yr. (Steel and Baird 1968; Campbell and Bate 1988; Heymans and MacLachlan 1996; Cahoon et al. 2017).

#### **Dunes (vegetated)**

Dunes are dynamic habitats where vegetation growth can often be limited due to harsh environmental conditions. Vegetation productivity is often limited due to poor nutrient content of dune soils and additional physical constraints such as inadequate freshwater supply, salt spray, wind/sand abrasion and excessive soil temperatures (McLachlan and Brown 2006; Frosini et al. 2012). Average annual NPP rates for dune plant productivity derived from two studies is 1,963 lbs. ac/yr ranging from 1,695-2,444 lbs. ac/yr.

# **Oyster reefs**

Oyster reefs play a fundamental role in nutrient cycling in coastal marine waters (Sanchez et al. 2015). As filter feeders, oysters are able to control primary productivity and phytoplankton community structure (Sanchez et al. 2015). Even at modest levels, oyster reefs can greatly decrease phytoplankton abundance (Plutchak et al. 2010). Oysters remove phytoplankton from water column but can supply nutrients from excretion to stimulate primary production further offshore. As oyster only indirectly affect primary productivity and predominantly reduce primary productivity at the local scale, they will not be ranked for NPP rates.

# **Rookery Islands**

No data found for NPP rates on rookery islands.

## **Step D - Hazard Mitigation Application**

After completing the preceding steps, Step D provides a synthesis of the information determined up to this point and how it relates to hazard mitigation funding. Step D also includes a list of potential hazard mitigation funding opportunities developed to help a project proponent determine potential opportunities that may be available for funding applications. The list of opportunities includes eligibility requirements for each program and lists key considerations that may play a role in developing a Benefit Cost Analysis, if needed, for the application.



## Synthesizing Steps A, B, and C

At this point, the project proponent will have completed Steps A, B, and C to determine the appropriateness of the project as a nature-based solution for hazard mitigation funding, the level of exposure to particular hazards at the project site, and the ecosystem service benefits that could result after implementing the project. The project proponent should use Table 8-3 to record and evaluate the results from each step.

**Step A** – Respondent should be able to respond "Y" to each of the questions to determine if the project meets the intent of the hazard mitigation funding opportunities approach

**Step B** – Respondent should check the box for each hazard ranking based on the project location on the Risk Index maps. The result of each hazard ranking is shown in Table 8-1.

Table 8-1. Project Capacity to Benefit Hazard Mitigation Based on Risk Index Maps

Low	Project in its current construct may have low likelihood to benefit hazard mitigation and meet Federal and/or State eligibility requirements for a variety of mitigation programs at its location.
Low-Medium	Project in its current construct may have low-medium likelihood to benefit hazard mitigation and meet Federal and/or State eligibility requirements for a variety of mitigation programs at its location.
Medium	Project in its current construct may have medium likelihood to benefit hazard mitigation and meet Federal and/or State eligibility requirements for a variety of mitigation programs at its location.
Medium-High	Project in its current construct may have medium-high likelihood to benefit hazard mitigation and meet Federal and/or State eligibility requirements for a variety of mitigation programs at its location.
High	Project in its current construct may have high likelihood to benefit hazard mitigation and meet Federal and/or State eligibility requirements for a variety of mitigation programs at its location.

Projects classified as low or low-medium are likely to not be appropriate for hazard mitigation funding. Projects classified as medium may be appropriate for hazard mitigation funding but should be considered on a case-by-case basis. Projects classified as medium-high or high are likely appropriate for hazard mitigation funding.

**Step C** – Respondent should use the Step C section to tabulate the regulating services and co-benefits scores achieved by the project. The "Notes" box should be used to list benefits that should be discussed qualitatively in a hazard mitigation funding application. The outputs for each project by score are listed in Table 8-2.

Table 8-2. Project Capacity to Offer Ecosystem Services to Benefit Hazard Mitigation

Regulating services score	Result
0-5	Project offers minor ecosystem service benefits for hazard mitigation. These could be discussed qualitatively for the purposes of a hazard mitigation grant funding application.
6-10	Project offers moderate ecosystem service benefits for hazard mitigation. These could be discussed qualitatively for the purposes of a hazard mitigation grant funding application. In specific situations, a quantitative cost-benefit analysis could be pursued.
11+	Project offers significant ecosystem service benefits for hazard mitigation. There is a potential to evaluate these further through a cost-benefit analysis.
Co-benefits score	Result
1-4	Project offers minor co-benefits. These could be discussed qualitatively for the purposes of a hazard mitigation grant funding application.



Co-benefits score	Result
5-8	Project offers moderate co-benefits. These could be discussed qualitatively for the purposes of a hazard mitigation grant funding application.
9-11	Project offers significant co-benefits that can be discussed qualitatively for a hazard mitigation grant funding application. In specific situations, a quantitative analysis could be pursued through a cost-benefit analysis.

This information can be used to develop a hazard mitigation funding application for one or more of the hazard mitigation grant programs listed in  $\mathbf{Step}\ \mathbf{D}$ .



Table 8-3. Tabulate Results from Steps A, B, and C

peral Project seessment  e project reduce e and property to g natural disast is (e.g., coastal or ne flooding)?  project enhance, or support stems through amages (i.e., is to project a pased solution)?  by funded or not funded)  roject in an early ning phase?  putual, preliminary permitting, final	oy er r ee, he	Land Lo	oss Risk lex I Risk	Low			m Medium	Mediu	ım-High	Н	igh
e and property by general disastic (e.g., coastal or ne flooding)?  project enhance, or support stems through amages (i.e., is toroject a passed solution)?  y funded or not funded)  roject in an early ning phase?  patual, preliminary	oy er r ee, he	Land Lo	oss Risk lex I Risk	Low	Low	/-Mediui	m Medium	Mediu	ım-High	H	gh
te, or support stems through amages (i.e., is to project a passed solution)? To project in need of funding? Sy funded or not funded)  roject in an early ning phase?  Stual, preliminary	he ?	Flood	lex I Risk					li			
funding?  y funded or not funded)  roject in an early ning phase?  stual, preliminary			-								
ning phase? otual, preliminary	У		lex								
, shovel ready)		Wave A	Action ndex								
		If the project achieves a medium to high score for at least one hazard, proceed to Step C.									
				Step C							
ng services sco	re	Co-benefits score									
services Sco			Score	Supporting services		Score	Cultural services	Score			Score
surge / protection				Habitat provision	I		Ecotourism		Grazin	g/	
control / eline zation				Species richness			Recreation				
lignment tions				Listed species							
				Critical habitat							
				Primary productivit	ty						
s s s s s s s s s s s s s s s s s s s	g services sco services Sco surge / rotection control / elline tignment	surge / Control / Sequence on trol / Seline seation signment	g services score  services Score Regulating services  surge / Carbon sequestration  control / Bline ration  ignment	g services score  services Score Regulating services  Gurge / Carbon sequestration  control / Bline aution  ignment	Step C  g services score  services  Score Regulating services  Surge / Carbon sequestration  Control / Beline ration  ignment ions  services  A services  Score Regulating services  Score Supporting services  Supporting services  Supporting services  Listed species  Critical habitat  Primary	Step C  g services score  Regulating services  Supporting services  Surge / Carbon sequestration  Control / Beline ration  Gignment ions  at least of the step C  Step C  Supporting services  Surge / Supporting services  Supporting services  Supporting services  Supporting services  Supporting services  Supporting services  Listed species  Critical habitat	Step C  g services score  Regulating services  Score Regulating services  Supporting services  Frotection  Species richness  Listed species  Critical habitat  Primary	Step C  g services score  Regulating services  Carbon sequestration  Control / eline ration  ignment ions  services  Step C  Co-benefits score  Co-benefits score  Supporting services  Score Cultural services  Score Supporting services  Score Supporting services  Score Supporting services  Score Cultural services  Score Supporting services  Critical habitat  Primary	Step C  g services score  Regulating services  Co-benefits score  Score Regulating services  Supporting services  Footourism  Footourism  Footourism  Score services  Footourism  Footouri	Step C  g services score  Score Regulating services  Carbon sequestration  Species richness  Control / Beline action  Gignment ions  at least one hazard, proceed to Step C.  Step C  Co-benefits score  Co-benefits score  Supporting services  Score Cultural services  Score Supporting services  Score Supporting services  Score Supporting services  Score Cultural services  Score Supporting services  Score Supporting services  Score Supporting services  Score Cultural services  Score Provision  Fisheric Grazin  Timbo	Step C  g services score  Score Regulating services  Supporting services  Score Supporting services  Surge / rotection  Species richness  Species richness  Critical habitat Primary  Step C  Co-benefits score  Cultural services  Score Provisioning services  Fisheries / Grazing / Timber

Total score

Notes

### Table 8-4. Hazard Mitigation Funding Sources

Entity	Funding Program	Type of Funding	Funds Available for	Pre-requisites	Federal Cost Share	Project Examples	Ecosystem Services	Other Notes	Link	Literature Related to Ecosystem Systems
FEMA	Hazard Mitigation Grant Program (HMGP)	Mitigation	States, local communities, tribes, territories	Hazard Mitigation Plan	75% (90% for small and impoverished communities)	Acquisition, elevations, floodproofing structural retrofits for flood, earthquake, wind, wildfire resilience, drainage improvements, slope stabilizations	ecosystems to be resilient to	May require pre-approval for use of any BCA that is not their BCA, including inclusion of other benefits	https://www.fema.gov/hazard- mitigation-grant-program	-
FEMA	Flood Mitigation Assistance (FMA)	Mitigation	States, local communities, tribes, territories	Hazard Mitigation Plan	Up to 75% in most cases; however, FEMA may cover 100% in severe repetitive loss cases and 90% in repetitive loss cases	Project Scoping, flood control, floodwater storage and diversion, floodplain and stream restoration, stormwater management, wetland restoration/creation,	Regulating Services - Protect from extreme events by building protection before event; Cultural Services - Preventing damage from weather events does not negatively impact tourism	May require pre-approval for use of any BCA that is not their BCA, including inclusion of other benefits	https://www.fema.gov/grants/mitigatio n/floods	-
FEMA	Building Resilient Infrastructure and Communities (BRIC)	Mitigation	States, local communities, tribes, territories	Must prove Community Lifelines	75% (90% for small and impoverished communities)	Nature-Based Solutions (NBS), tsunami evacuation, infrastructure upgrades, stormwater management, landslide mitgation, drainage improvements, structural retrofits, elevations, acquisitions/demolitions	Regulating Services - Protect from extreme events by building protection before event; Cultural Services - Preventing damage from weather events does not negatively impact tourism	May require pre-approval for use of any BCA that is not their BCA, including inclusion of other benefits	https://www.fema.gov/BRIC; https://www.govtech.com/em/prepared ness/BRIC-Expanding-the-Concepts-of- Federal-Pre-Disaster-Mitigationhtml	https://www.fema.gov/sites/def ault/files/2020- 08/fema_riskmap_nature-based solutions-guide_2020.pdf
NFWF/ NOAA	National Coastal Resilience Fund (NCRF)	Conservation	Coastal communities	-		Coastal marshes and wetlands, dune and beach systems, oyster and coral reefs, forests, coastal rivers and floodplains, barrier islands	Regulating Services - Protect from extreme events by building protection from event; Cultural Services - Preventing damage from weather events does not negatively impact tourism; Supporting Services - Protection can create habitats for species	to advance permitting, NBS to enhance coastal resilience	https://www.nfwf.org/programs/nationa l-coastal-resilience-fund	https://www.nfwf.org/sites/def ault/files/coastalresilience/Docu ments/regional-coastal- resilience-assessment.pdf
GLO	U.S. Department of Housing and Urban Development (HUD) Community Development Block Grant Mitigation Funds (CDBG- MIT): 2015 and 2016 Floods State Mitigation Competition	Mitigation	Cities, counties, tribes, COGs with a focus on Low-and-Moderate Income populations	Designated as Most Impacted and Distressed (MID) area by HUD/State	-	Flood control and drainage improvements, infrastructure improvements, green infrastructure, buyouts, public facilities	Regulating Services - Moderation of extreme events	\$46.1 million for 2015 floods, \$147.7 million for 2016 floods	https://recovery.texas.gov/mitigation/in dex.html	-
GLO	U.S. Department of Housing and Urban Development (HUD) Community Development Block Grant Mitigation Funds (CDBG- MIT): Hurricane Harvey State Mitigation Competition Round 1	Mitigation	Cities, counties, tribes, COGs, state agencies, port authorities, river authorities, special purpose districts with a focus on Low-and- Moderate Income populations	Coastal counties affected by Hurricane Harvey	-	Flood control and drainage improvements, infrastructure improvements, green infrastructure, buyouts, public facilities	Regulating Services - Moderation of extreme events	\$2.1 billion total over life of competition (\$1 billion for Round 1)	https://recovery.texas.gov/mitigation/competitions.html	-
GLO	U.S. Department of Housing and Urban Development (HUD) Community Development Block Grant Disaster Recovery Funds (CDBG-DR) Local Infrastructure Program	Mitigation	Regional COGs based on a HUD approved needs assessment	Areas affected by Harvey		Flood control and drainage reapir and improvements, restore infrastructure, demolition, economic development, public service	change;	-	https://recovery.texas.gov/local- government/programs/local- infrastructure/index.html	-

Entity	Funding Program	Type of Funding	Funds Available for	Pre-requisites	Federal Cost Share	Project Examples	Ecosystem Services	Other Notes	Link	Literature Related to Ecosystem Systems
FHWA	Nature Based Resilence for Coastal Highways	Mitigation	DOTs, MPOs, local agencies, Federal land management agencies	Coastal highways	-	Shoreline stabilization, floodplains affecting coastal highways, planning for climate change (management cycles, life cycle costs), vulnerability and risk assessments	Regulating Services - Moderation of extreme events	-	https://www.fhwa.dot.gov/federalaid/1 20924.cfm	-
DOI	Natural Resource Damage Assessment (NRDA)	Restoration	State, tribal, and federal trustee agencies	Oil spill/hazardous materials	-	The addition of habitat to Fish and Wildlife Service Refuges, National Parks, state parks and tribal lands, invasive species control, fish passage in streams and rivers, construction of bird nesting islands, wetland, saltmarsh, and eel grass bed restoration, endangered mussel reintroductions		Average of \$2 million annually	https://www.doi.gov/restoration	-
EPA	Wetland Program Development Grants (WPDGs)	Restoration	States, tribes, local governments, interstate agencies, intertribal consotia, eligible universities that are agencies of a state government	-	EPA will fund 75% of project cost	Increased quality and quantity of wetlands, improved wetlands effort, improved wetland inventories and baseline condition assessments to address hazard mitigation, improved data to use in modeling potential hydrologic change, wetland lossess or increases	Regulating Services - Local climate and air quality, waste-water treatment; Supporting Services - Habitats for species	\$1,200,000 for FY 2020 projects	https://www.epa.gov/sites/production/f iles/2020- 05/documents/fy20 region 3 wpdg rfa _final_2020_may_19.pdf	-
NOAA	Effects of Sea Level Rise Program (ESLR)	Restoration	Scientists, management officials	-	-	Post-Hurricane Dorian Data Collection to Improve Understanding of Beach, Dune Recovery Following Storms, Evaluating the Resilence of North Carolina Natural and Living Shorelines following Hurricane Dorian	Regulating Services - Moderation of extreme events	Prioritized events: weather- related events, anthropogenic associated events including episodic events (e.g.,flood driven opening of a water diversion)	https://coastalscience.noaa.gov/researc h/coastal-change/ecological-effects-sea- level-rise-program/	
NOAA	Adaptation Science Program (AdSci)	Research/ Planning	U.S. Coastal communities	-	-	-	Regulating Services - Moderation of extreme events; Cultural Services - Tourism	AdSci will seek to fund a combination of 1 and 2 year projects in FY 21; proposals should include the costs of data sharing or archiving in their budgets	https://cpo.noaa.gov/Portals/0/Grants/2 021/AdSci_FY21_Program_Information_ Sheet_NOFO_Version.pdf	-
USACE	Continuing Authorities Program	Mitigation	Cities, counties, special authorities, or units of state government	-	Feasibility phase federally funded up to \$100,000; 50% share after	Streambank and shoreline erosion, beach erosion, hurricane and storm damage reduction, flood control, ecosystem restoration	Regulating Services - Flood control and erosion reduction allows ecosystems to be resilient to change; Cultural Services - Preventing damage from weather events does not negatively impact tourism; Supporting Services - Protection can create habitats for species	-	https://www.nae.usace.army.mil/Missio ns/Public-Services/Continuing- Authorities-Program/	-

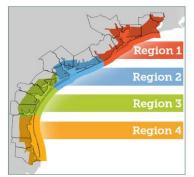
Entity	Funding Program	Type of Funding	Funds Available for	Pre-requisites	Federal Cost Share	Project Examples	Ecosystem Services	Other Notes	Link	Literature Related to Ecosystem Systems
NRCS	Emergency Watershed Protection (EWP) Program Recovery Assistance	Mitigation	Public and private landowners can apply through a local sponsor: cities, counties, towns, conservation districts, flood and water control districts, or any federally- recognized Native American tribe or tribal organization	-	75%	Reapir levees and structures, debris removal from stream channels, road culverts, reshape and protect eroded streambanks, correct damaged drainage facilities	change;	-	https://www.nrcs.usda.gov/wps/portal/ nrcs/detailfull/national/programs/landse ape/ewpp/?cid=nrcseprd1381472	

#### Additional Sources:

- 1. National Park Service Save America's Treasures: https://www.nps.gov/preservation-grants/sat/
- 2. Environmental Protection Agency Building Blocks for Sustainable Communities: https://www.epa.gov/smartgrowth/building-blocks-sustainable-communities
- 3. U.S. Department of Agriculture Rural Community Development Initiative Grants: https://www.rd.usda.gov/programs-services/rural-community-development-initiative-grants
- 4. Environmental Protection Agency National Estuary Program Coastal Watershed Program: https://estuaries.org/initiatives/watershedgrants/
- 5. Federal Highway Administration Transportation Emergency Relief Program: https://www.fhwa.dot.gov/programadmin/erelief.cfm
- 6. Economic Development Administration Public Works and Development Facilities: https://www.eda.gov/funding-opportunities/
- 7. Economic Development Administration Economic Adjustment Program: https://www.eda.gov/funding-opportunities/
- 8. U.S. Department of Agriculture Watershed and Flood Prevention Operations Program: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/landscape/wfpo/?cid=nrcs143\_008271
- 9. Natural Resources Conservation Service Watershed Rehabilitation Program: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/landscape/wr/?cid=nrcs143\_008448
- 10. National Fish and Wildlife Foundation Acres for America: https://www.nfwf.org/programs/acres-america

# **Appendix A**

# **Ecosystem Services Literature Review Matrix of Studies by Region in Texas**



<b>Counties by Region</b>			
Region 1	Region 2	Region 3	Region 4
Brazoria	Calhoun	Aransas	Cameron
Chambers	Jackson	Kleberg	Kenedy
Galveston	Matagorda	Nueces	Willacy
Harris	Victoria	Refugio	
Jefferson		San Patricio	
Orange			

Habitats of interest	Bluevalue (formerly GECOSERVE
Oyster reefs	check
Coastal wetlands	check
Coastal bottomland forests	no data
Mangroves	no data
Coastal Priaries	no data
Beaches	check
Dunes	check
Seagrass	check

Ecosystem Services	Region 1	Region 2	Region 3	Region 4
Provisioning				
Regulating*				
Cultural				
Supporting*				

<sup>\*</sup>Regulating and supporting services are highligted in yellow as they are considered high priority services to target

	VALUATION METHODS
Avertive or Mitigative Expenditures	Expenditures taken to mitigate or avert the negative effects of the loss of ecosystems or ecosystem services and to avoid consequent economic costs. These expenditures can be used as indicators of the value of conserving habitats in terms of expenditures avoided.
Benefit Transfer (BT)	The goal is to estimate benefits for one study by adapting an estimate of benefits from some other study. It is often used when it is too expensive and/or there is little time available to conduct an original valuation study.
Choice Experiment (CE) or Discrete Choice Experiment DCE)	Choice experiments are based on Lancastrian consumer theory which proposes that consumers make choices not on the simple marginal rate of substitution between goods, but based on preferences for attributes of these goods. CE predicts consumers' choice by determining the relative importance of various attributes in consumers' choice process (Hanemann an Kanninen 1998).
Contingent Valuation (CV) Damage Cost Avoided (DCA	Naminien 12396). People are directly asked their willingness to pay or accept compensation for some change in ecological service.  The damage cost avoided estimate the costs of ecosystem services based on avoiding damages due to lost services.
ebt for Nature Swap	Debt for nature swap is an agreement between a developing country with a high financial debt and one or more of its creditors. In this situation, the creditors agree to forgive the debt and in return the nation in debt promises environmental protection of some of its natural resources; historically the environmental promises have focused on the protection of large areas such as tropical rainforests (Wynn, 2011).
Delphi Panel	Structured communication technique created as an interactive forecasting method that relies on a panel of experts. This method is based on the idea that group judgments are more legitimate than individual judgments.
Demand Function	Demand function is a behavioral relationship between the quantity of a product (or service) consumed and a person's maximum willingness to apy for incremental increases in the quantity of such product (or service). Factors that frequently influence willingness-to-pay include income, price or availability of substitutes, and individual tastes or preferences. This behavioral relationship is usually an inverse relationship where higher prices lead to less quantity consumed and vice versa.
Discrete Factor Method DFM)	This method permits us to account for unobserved heterogeneity across agents, while at the same time allowing for correlation across RP and SP demand equations.
Emergy	Emergy is a thermodynamic methodology introduced by Howard Odum during the 1980s. This quantitative analysis techniquistandardizes the values of non-monetized and monetized resources, services and commodities in a sole unit, making it a veriversatile technique that can be applied to whatever natural or human system or to a mix of two and that allows measuring the work of the environment and economy on a common basis (Odum and Odum, 2000; Vassallo et al., 2013).
inergy Analysis (EA)	This valuation technique looks at the total biological productivity of ecosystems as a measure of their total contributory value. Primary plant production is the basis for the food chain which supports the production of economically valuable products such as fish and wildlife. It is converted to an equivalent economic value based on the cost to society to replace this energy source with fossil fuel as measured by the overall energy efficiency of economic production.
xpected Damage Function approach (EDF)	This method is used when the ecosystem has a protective value, such as the protecting value of coastal wetlands from storn or floods. In this case, the natural resource has a non-marketed service of protection of economic activity, property, or even people's lives by mitigating the storm effects. This method assumes that the value of the ecosystem in reducing economic impacts can be measured by the decrease in expected damages (Hanley & Barbier, 2009).
xpenses on Wildlife Habitat ledonic Price Method (HP)	It represents the costs incurred by recreational users of the habitat (Howde & Leitch, 1994). This method is used to value ecosystems or ecosystem services that directly affect market prices. It is commonly used in analyzing variations in house prices that reflect the home owner's willingness to pay for environmental attributes; it can be used to estimate the benefits associated with environmental amenities, such as aesthetics and proximity to recreational locations (King & Mazzotta, 2000).
nVEST: Integrated Valuation of Environmental Services and Tradeoffs	InVEST is a set of tools to map and value ecosystem services which are essential for sustaining and fulfilling human life. For more information visit: <a href="https://www.naturaicapitalproject.org/inVEST.html">https://www.naturaicapitalproject.org/inVEST.html</a> .
atent Class Model (LCM)	This method is used to evaluate choice behavior as a function of visible features of the choices and hidden heterogeneity in respondent characteristics.
Market Price (MP)	It estimates the economic value of ecosystem products or services that are bought and sold in commercial markets. It uses standard economic techniques for measuring the economic benefits from marketed goods, based on the quantity people purchase at different prices.
Meta-Analysis (MA)	The process or technique of synthesizing research results by using various statistical methods to retrieve, select, and combin results from previous studies.
Meta-Regression (MR)	A statistical model to perform meta-analysis that looks at the relation between values of x (dependent variable) given the observed values of y (independent variable(s)).
Multi-Model Criteria Analysis MCA)	A tool in decision theory that models a decision-maker preferences to choose among options involving a number of, often, conflicting goals. This approach examines how all the significant aspects of choices are assessed and traded-off by decision makers.
Multinomial Logit Model MNL)	This method is used to represent choice between two exclusive options; for example, a person may choose to drive to work and take a bus. The weakness of this model is that is implies that the choice between any two alternatives depends only on the characteristics of the alternatives being compared, rather than the characteristics of any other group of alternatives.
Opportunity Cost	The loss of potential gain from other alternatives when one alternative is chosen. In short, the benefits an individual would receive by choosing another action/buying another product.
Productivity Method (PM) landom Utility Model (RUM)	Estimates economic values for ecosystem products or services that are bought and sold in commercial markets. This method is used in travel cost recreation demand analysis to value features of the recreational sites. For example, this method can be used to value the benefits of improved access to beach or improved water quality for recreational purposes. The travel cost RUM analyzes a person's discrete choice of one recreation site over other sites. The site choice is assumed to depend on the features of the site and to reveal the person's preferences for those features.
tegression Analysis (RA)	The description of the nature of the relationship between two or more variables; it is concerned with the problem of describing or estimating the value of the dependent variable on the basis of one or more independent variables.
elative Ratings	describing or estimating the value of the dependent variance on the deason of one or more independent variance.  In this method individuals rate natural resources as a means of estimating its value. If a wettand provider fish for example are fish is highly valued, then they would rate the wetland with a 5, which would represent the highest level of relative importance.
eplacement Cost (RC) evealed Preference	The loss of a natural system service is evaluated in terms of what it would cost to replace that service.  This theory is based on the idea that the preferences of consumers can be revealed by their purchasing habits. Two method: that follow in this category are Travel Cost Method (TC) and Hedonic Price (HP).
hadow Price (SP)	Shadow price is a proxy value of a good, usually defined as what an individual must give up to gain an extra unit of that good. When the price of a good or service does not reflect the actual value of that good or service, or when there is no market for that good or service, shadow price can be used. Economists also use the term shadow price to refer to opportunity cost.
itated Preference	This technique is a market research tool that allows researchers to understand how consumers value different ecosystem products and/or services. It involves asking consumers to rate, rank, or how much they would be willing to pay or accept for certain ecosystem good or service. The choices made by consumers help determine how they value a certain product or service. Examples of this technique include contingent valuation, conjoint analysis, and choice experiment.
ravel Cost Method (TC)	Estimates conomic values associated with ecosystems or sites that are used for recreation. Assumes that the value of a site is reflected in how much people are willing to pay to travel to the site.
Willingness-to-Pay (WTP)	Asks people to directly state their willingness to pay for specific environmental services, based on a hypothetical scenario.

Region 1 Sources

ource	Authors	Date	Title	Location	Valued habitats	Ecosystem Services	Dollar Value estimated	Units	Ecosystem Service Categorization	method	download paper
			The economic value of								
			improving the								
			environmental quality of	Galveston Bay,							
1	Whittington et al.	1994	Galveston Bay	Texas	Coastal wetlands	Recreation		US\$ 2019 /per year	Cultural services	BT, CV	yes
						Storm surge protection	\$ 8,389.50	US\$ 2019 /per ha	Regulating services	RC	yes
			The Economic Value of			Dellution Abstoment	\$ 186.83	US\$ 2019 /per ha	Dogulating convices	RC	
			Ecosystem Services			Pollution Abatement	\$ 186.83	/per year	Regulating services	KL	yes
			Provided by the								
			Galveston Bay/Estuary					US\$ 2019 /per ha			
2	Ko et al.	2007	System	Galveston Bay	Coastal wetlands	Habitat	\$ 8,675.10	/per year	Supporting services	RC	yes
								US\$ 2019 /per ha			
						Recreation	\$ 5,771.50	/per year	Cultural services	BT	yes
			Salt Marsh Zonal			Gas Sequestration, Storage, and		US\$ 2019 /per ha			
			Migration and Ecosystem			Production	\$ 1,493.45	/per year	Regulating services	BT	yes
			Service Change in					US\$ 2019 /per ha			
			Response to Global Sea			Storm surge protection	\$ 5,625.92	/per year	Regulating services	ВТ	yes
			Level Rise: A Case Study	Galveston Island,				US\$ 2019 /per ha			
2	Feagin et al.	2010	from an Urban Region	Texas	Coastal wetlands	Habitat	\$ 8.829.80	/per year	Supporting services	вт	yes
	reagin et al.	2010	ITOTT all Orbait Kegion	TEXAS	Coastal Wetlands	Trabitat	7 0,020.00	/per year	Supporting services	ы	yes
							\$8 million of avoided				
							damages in coastal				
							protection under future	11667			
			Character than Dalissans at			Storm surge protection	emission scenarios	US\$/year?	Regulating services	avoided damages	yes
			Changes in the Delivery of				\$3 million-\$31 million of				
			Ecosystem Services in			C Cti Ct	damages incurred				
	Constant at al	2015	Galveston Bay, TX, under	Calmata Ban	Caratal	Gas Sequestration, Storage, and Production	depending on migration potential of marsh and SLR	LICC 2010	Description of the same	d	
4	Guannel et al.	2015	a Sea-Level Rise Scenario	Galveston Bay	Coastal wetlands	Production	Loss of freshwater	05\$ 2010	Regulating services	damages incurred	yes
							wetlands due to SLR will				
							results in \$40 million of				
							lost services; loss of				
							saltmarsh due to SLR will			BT - ordinary least	
						Storm surge protection, pollution	result in \$11 million of lost		Regulating and cultural	square regression,	
						abatement, recreation, aesthetics	services	US \$ 2008	services	metaregression	ves
						abatement, reareation, aestricties	Je. vices	03 \$ 2000	SCITICES	_	705
										BT - ordinary least	
										square regression,	
						Storm surge protection	\$ 238,668,435.00	US \$ 2008 per ha	Regulating services	metaregression	yes
										BT - ordinary least	
										square regression,	
						Pollution Abatement	\$ 167,434,273.00	US \$ 2008 per ha	Regulating services	metaregression	yes
										DT	
			Integrated ecosystem							BT - ordinary least	
			services assessment:			Regrestion	\$ 34.546.618.00	UC ¢ 2000 por ho	Cultural comicas	square regression,	
			Valuation of changes due			Recreation	\$ 34,546,618.00	US \$ 2008 per ha	Cultural services	metaregression	yes
			to sea level rise in							BT - ordinary least	
_	V 1 % 1 1	2046	Galveston Bay, Texas,	Galveston Bay,			4 24 274 775 00	LIC 6 2000	c li i	square regression,	
5	Yoskowitz et al.	2016	USA	Texas	Coastal wetlands	Aesthetics		US \$ 2008 per ha	Cultural services	metaregression	yes
							Bay would be willing to				
			L				pay \$15.73 per square				
			Global change—Local				mile to conserve		Study does not consider a		
			values: Assessing				freshwater marshes, and	20/ 1:	specific ecosystem service.		
			tradeoffs for coastal		Coastal wetlands -	Lucius I S C I I I	\$2.54 per square mile to	Using a 3% discount	But looks at willingness to		
_	L.,		ecosystem services in the		freshwater	Willingness to Pay for restoring and	preserve undeveloped	rate, over a 10-year	pay for restoration of	WTP, Discrete choice	
6	Hindsley and Yoskowitz	2020	face of sea level rise.	Texas	marshes	conserving coastal habitat under SLR	upland area to facilitate	payment period	marshes in light of SLR	experiemts	yes

#### Region 3 Sources

									Ecosystem Service		downloade
ırce Authors	Da	ite	Title	Location	Valued habitats	Ecosystem Services	Dollar Value estimated	Units	Categorization	method	paper
			Selected Recreational Values of the			Recreation (sport					
			Corpus Christi Bay National Estuary	Corpus Christi Bay		fishing, wind surfing					
1 Wellman and	d Noble 1	1997	Program Study Area	National Estuary	Estuary	and bird watching)	\$ 83 mil, \$93k, \$4.6 mil	US\$ 1997/per year	Cultural services	TC	yes
			Malaina Barah Classina an the Badas	Dadus Island National				LICÉ 2010 / /		Davis alad	
	_	- 1	Valuing Beach Closures on the Padre					US\$ 2019 /per person /per		Revealed	
2 Parsons and	Kang 2		Island National Seashore	Seashore	Beaches	Recreation	\$ 38.34	visit	Cultural services	preference, RUM	yes
		- 1	Compensatory Restoration in a								
		- 1	Random Utility Model of Recreation								
			Demand. Contemporary Economic	Padre Island National							
3 Parsons and	Kang 2	2010	Policy	Seashore	Beaches	Recreation	\$ 108.53	US\$ 2019 /per trip	Cultural services	TC	yes
						Nutrient Cycling	\$ 5,242,755.00	US\$ 2012 /per year	Supporting services	PM, RC	yes
			Linking ecological function and		Coastal wetlands	Recreation		US\$ 2012 /per year	Cultural services	MP, TC	yes
			ecosystem service values of			Nutrient Cycling		US\$ 2012 /per year	Supporting services	PM, RC	yes
			estuarine habitat types associated		Oyster reefs	Recreation	\$ 81,000.00	US\$ 2012 /per year	Cultural services	MP, TC	yes
			with a barrier island system	Mustang Barrier Island at		Nutrient Cycling	\$ 12,054,095.00	US\$ 2012 /per year	Supporting services	PM, RC	yes
4 Francis	2	2012		Corpus Christi	Seagrass	Recreation	\$ 81,000,000.00	US\$ 2012 /per year	Cultural services	MP, TC	yes
			Dala and Malus of Nitura								
		- 1	Role and Value of Nitrogen								
		- 1	Regulation Provided by Oysters								
			(Crassostrea virginica) in the Mission				1.	US\$ 2012 /per ha /per			
5 Beseres et a	. 2	2013	Aransas Estuary, Texas, USA	Mission-Aransas Estuary	Oyster reefs	Nutrient Regulation	\$ 173.00	year	Regulating services	RC	yes
			Assessment and monetary valuation								
			of the storm protection function of								
			beaches and foredunes on the Texas	Mustang and North		Storm surge					
6 Taylor et al.	2	2015	Coast	Padre Islands	Beaches and dunes	protection	\$141.4 million/6.89km2	ha	Regulating services	RC	ves

#### **Region 4 Sources**

									Ecosystem Service		downloaded
Source	Authors	Date	Title	Location	Valued habitats	Ecosystem Services	Dollar Value estimated	Units	Categorization	method	paper
			Valuina Danah								
			Valuing Beach								
			Closures on the					cd 2040 /			
				Padre Island				US\$ 2019 /per person			
1	Parsons and Kang	2007	National Seashore	National Seashore	Beaches	Recreation	\$ 38.34	/per visit	Cultural services	Revealed preference, RUM	yes
			Compensatory								
			Restoration in a								
			Random Utility								
			Model of								
			Recreation	Padre Island							
2	Parsons and Kang	2010	Demand.	National Seashore	Beaches	Recreation	\$ 108.53	US\$ 2019 /per trip	Cultural services	тс	yes
								, ,, ,			ľ
			Assessment and								
			monetary valuation								
			of the storm								
			protection function								
			of beaches and								
				Marston a and North	Danahasand						
_	.L		foredunes on the	Mustang and North							
3	I Taylor et al.	2015	Texas Coast	Padre Islands	dunes	Storm surge protection	\$141.4 million	US\$ 2013/per year	Regulating services	RC	yes

#### Coastwide Sources

cousti.	ac Jources											
					Valued					Ecosystem Service		downloaded
Source	Authors	Date	Title	Location	habitats	Ecosystem Services	Dollar Val	ue estimated	Units	Categorization	method	paper
			Valuing									
			environmental									
			resources under									
			alternative									
			management regimes		Coastal							
1	Freeman III	1991		Texas coast	wetlands	Habitat for fisheries	\$			Supporting services	PM	yes
						Recreation	\$	171.18	US\$ 2019 /per visit	Cultural services	TC, WTP	yes
			The benefits of water			Recreation	\$	418.88	US\$ 2019 /per visit	Cultural services	TC, WTP	yes
			quality improvements									
			for marine recreation:									
			A review of the						US\$ 2019 /per person			
2	Freeman III	1995	empirical evidence	Texas coast	Beaches	Recreation	\$	5,370.64	/per year	Cultural services	TC, WTP	yes
				Gulf of Mexico Coastal								
				States: Alabama, Florida,								
				Louisiana, Mississippi,	Coastal				US\$ 2019 /per ha /per		DCA, Multiple Regression with Annual	
3	Costanza et al.	2008		Texas	wetlands	Storm surge protection	Ś	16.779.00		Regulating services	frequency of storms	ves
			·			Air quality	Ś	40.205.20		Regulating services	Urban Forest Effects (UFORE) model	ves
										0	This service was estimated using a	
			Forest Ecosystem								carbon value of \$22 per metric ton.	
			Values for Texas								Carbon storage was amortized over 20	
			coastal counties (see								years using a 3% discount rate to	
			webportal			Carbon sequestration	\$	123,710.10	US\$2011/year	Regulating services	determine an annual value	ves
			https://texasforestinf			Water capture, filtration and regulation	\$	1,116,034.90		Regulating services	?	yes
			o.tamu.edu/foresteco		Coastal	Biodiversity	\$	381,539.10	US\$2011/year	Supporting services	?	yes
4	Texas A&M Forest Serivce	2020	systemvalues/)	Texas coastal counties	forests	Cultural: recreation, spiritual, aesthetic	\$	1,597,368.40	US\$2011/year	Cultural services	WTP	yes

# **Appendix B Case Studies**



#### **Case Studies**

Over the course of the development of this methodology, it became apparent to the Planning Team that monetizing the benefits of ecosystem services is still an under-researched topic in Texas. The Texas coast is a unique environment in which some habitat types offer different values and benefits depending on the location of the habitat. As such, valuation techniques may not be easily translated across the coastal regions. Some studies are available for valuation estimates of habitats along the Texas coast as a whole, but many are older and likely need to be updated. Regional studies currently available may be applicable to proposed projects in the same areas, as monetary values can be transferred to regionally specific habitat types, but many are concentrated in the upper and mid-coast regions and date back as far as 1994. At this time, there are very few replicated and recent studies along the Texas coast from which a set of standard monetary values can be derived for coastal habitats. As the scope of this task relied on currently available literature to develop a defensible approach to quantifying the value of ecosystem services, no approach was put forth as part of this methodology at this time.

However, two case studies were chosen as pilot projects in an attempt to apply monetary values to ecosystem services provided by coastal habitats using the best available data. These case studies are included as an attachment to the methodology to provide examples of a potential method to monetize the benefits of ecosystem services. This is not included as part of the current methodology because the process is lengthy and the data is limited. As more research and literature become available, the approach can be refined and a standardized system for quantifying ecosystem services for coastal habitats across Texas can be developed. A description of the chosen projects and their benefits relative to hazard mitigation are included in this attachment. The data sources and valuation technique used to quantify these benefits are also included. All values were adjusted to US 2020 dollars for the purpose of this evaluation.



## Case Study 1: Portland Living Shoreline - Region 3

#### 1. Project Description:

This project would create a living shoreline near southwest Portland to prevent shoreline erosion and enhance wetland habitats. The living shoreline would include a shoreline stabilization structure, such as a rock breakwater, in addition to nature-based components, such as wetland plants, to mitigate the effects of erosion. This area of shoreline has degraded due to population growth and land use conversion, in addition to wind-driven erosion. Over the next 50 years, 5 acres of shoreline are projected to erode based on historic shoreline retreat rates if this project does not occur. This project would protect the 5 acres of shorelines that are projected to erode. The living shoreline would safeguard the roads, property, and infrastructure behind the shoreline, which would otherwise require relocation or abandonment based on current erosion trends. The project would serve as an example of living shoreline techniques to increase coastal resiliency in a highly visible location for the public.

The project is in **need of funding** and **provides beneficial ecosystem services**:

- Regulating services erosion control, shoreline stabilization, storm protection
- Supporting services habitat provision

### 2. Assigning a monetary value to the ecosystem services provided by the project:

- From the project cost templates (TCRMP 2019 technical report pg.706) obtained acreages of wetland habitat to be created: Project will create/enhance 50 acres of wetland habitats to protect 5 acres of shoreline projected to erode in the coming years. The project safeguards the roads, property, and infrastructure behind the shoreline.
- Used 'basic benefit transfer': which assumes that values are constant over ecosystem types

Assigning monetary value to the ecosystem services provided by the marsh:

Habitat Type	Ecosystem services provided	Literature Search for valuation studies specific to the Texas Coast – Region 3	Literature Search for valuation studies specific to the whole Texas Coast (US\$2020)	AECOM 2018 Tech Memo: Ecosystem Service Valuations (annual average value/acre/year in US\$2020)	Source for value estimates:
Coastal wetlands	Storm protection	NONE	\$6,927.10 (annual average/acre/year)	\$6,927.10	Costanza et al. 2008 (whole Texas Coast)
Coastal wetlands	Habitat (water quality)	NONE		\$207.90	Woodward and Wui 2001
Coastal wetlands	Habitat (fisheries)	NONE	\$5.02/ha/year or \$2.03/ac/year		Freeman 1991 (Whole Texas Coast)



# TOTAL Ecosystem Service VALUES: \$356,851.50 per year for 50 acres of created/enhanced wetland

- Total storm protection value for 50 acres of wetland: \$346,355.00 (US\$2020) estimated average value of hurricane storm hazard risk reduction provided by wetlands.
- Habitat (water quality): \$10,395 (US\$2020) and Habitat (fisheries): \$101.5 (US\$2020)



## Case Study 2: Galveston Island West of Seawall to 8 Mile Road Beach

## **Nourishment - Region 1**

#### 1. Project Description:

This project would provide 1 mile of shoreline stabilization along the Gulf beach of Galveston's West End. A feeder beach would also be created to passively nourish the shoreline from the Galveston Seawall to 8 Mile Road through natural transport. Recent nourishment efforts on Galveston Island were achieved through improved coordination of dredged materials between federal and state agencies. Continued coordination between federal and state agencies would keep costs feasible for this stretch of shoreline. Many of the Galveston Island beaches are experiencing heavy rates of erosion with shoreline losses ranging from 1.6 feet to 11.5 feet per year since the year 2000. The beach nourishment and protection of West Galveston Island, an area highly used by the public that generates important tourism benefits for the local economy, would preserve the recreational value for human use, as well as the natural habitat for wildlife.

The project is in need of funding and provides beneficial ecosystem services:

- Regulating services erosion control, shoreline stabilization, storm protection
- Supporting services habitat provision
- Cultural services recreation and tourism

#### 2. Assigning a monetary value to the ecosystem services provided by the project:

- From the project cost templates (TCRMP 2019 technical report pg. 718). This project would provide 1 mile by 25 feet (~3 acres) of shoreline stabilization along the Gulf beach of Galveston's West End.
- Used 'basic benefit transfer': which assumes that values are constant over ecosystem types

Assigning monetary value to the ecosystem services provided by the marsh:

Habitat Type	Ecosystem services provided	Literature Search for valuation studies specific to the Texas Coast – Region 1	Literature Search for valuation studies specific to the whole Texas Coast or other Regions (US\$2020)	AECOM 2018 Tech Memo: Ecosystem Service Valuations (annual average value/acre/year in US\$2020)	Source for value estimates:
Beach	Storm protection and erosion control	NONE	NONE	\$34,927.92 (applies to beaches and dunes that protect property)	Mendoza- Gonzalez et al. 2012 (Gulf of Mexico, Mexican Coastline)
Beach	Storm protection	NONE	\$159,227,729.77 /6.89km²/year (Region 3) = \$ 93,562.65/ac/year		Taylor et al. 2015

Beach	Habitat	NONE			
Beach	Recreation and aesthetics	NONE	NONE	\$20,166.72	Liu et al. 2010 (Meta- analysis for NJ coast)
Beach	Tourism (recreation)	NONE	\$5,476.66 per person /per year		Freeman 1995 (whole Texas coast
Beach	Tourism (recreation)	NONE	\$39.10 per person/per visit		Parsons and Kang 2007 (Region 3)

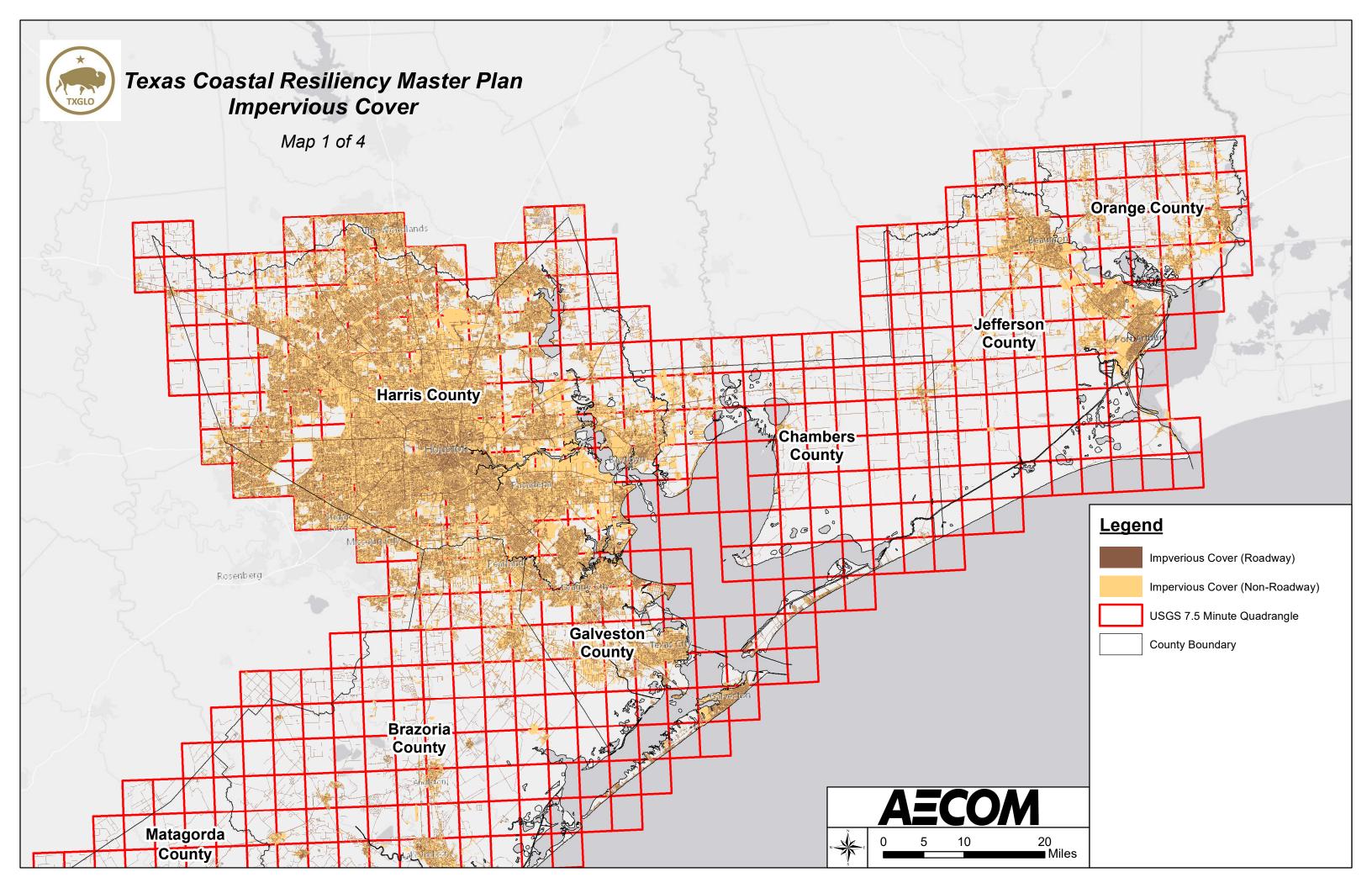
## TOTAL Ecosystem Service VALUES: \$341,188.12 per year for ~3 acres of shoreline stabilization efforts

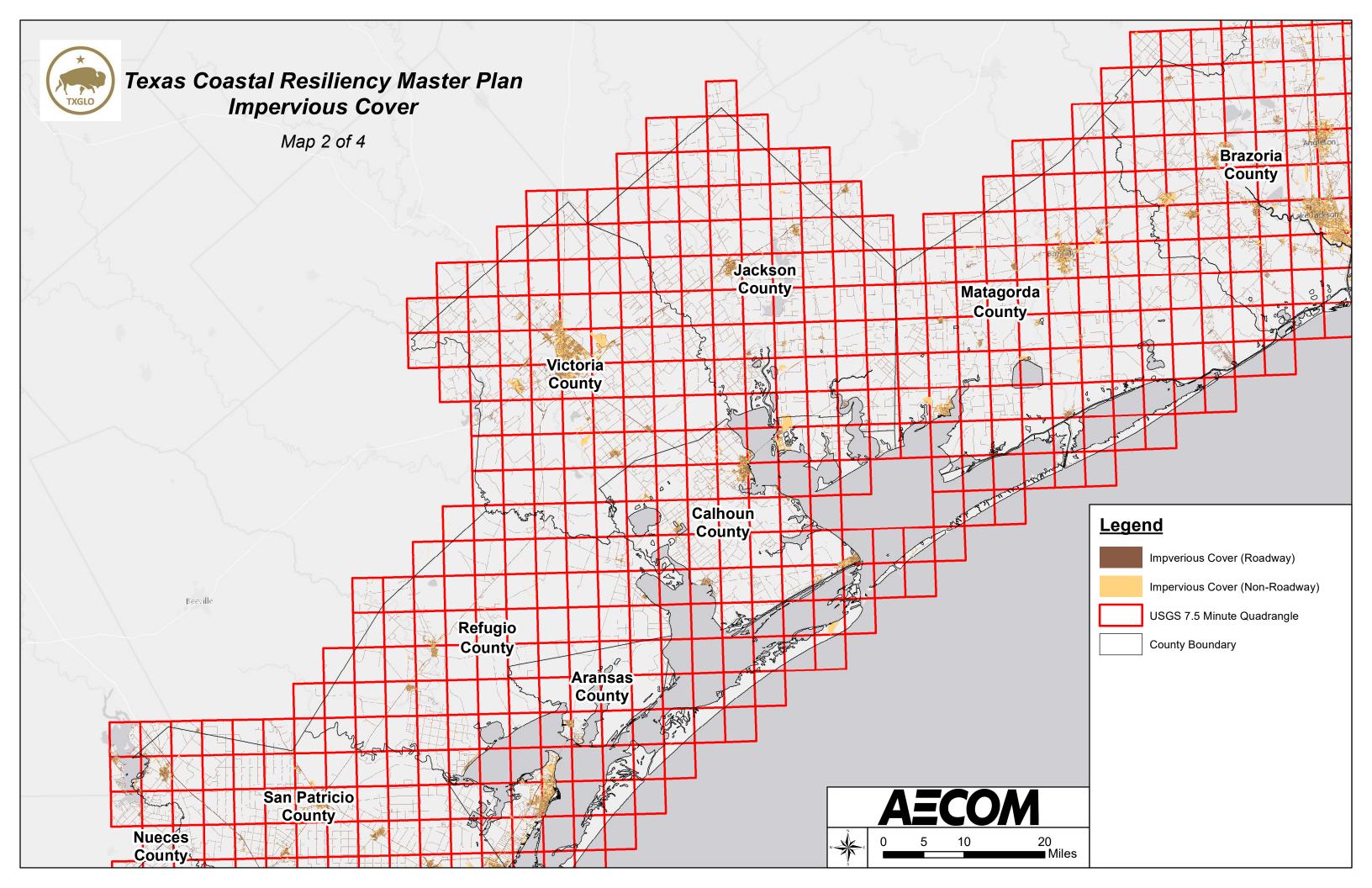
- Storm protection/erosion control: protection value from dunes/beaches US\$
   93,562.65/acre/year = \$ 280,687.96 for 3 acres of beach (took values from the Taylor et al. 2015 as that was calculated along the Texas Coast even though its for another Region. The Mendoza-Gonzalez et al. 2012 study calculated values for locations along the Mexican coast.
- Beach: Recreation: \$20,166.72 /acre/year = \$60,500.16 for 3 acres of beach restoration (Lui et al. 2010 – Meta-analysis for NJ coast)
- To refine the estimates for Tourism can use values calculated from Freeman 1995 and Parsons and Kang 2007 as those were calculated for the Texas Coast but need to know number of visitors per day or year for the specific beach in order to implement those numbers.

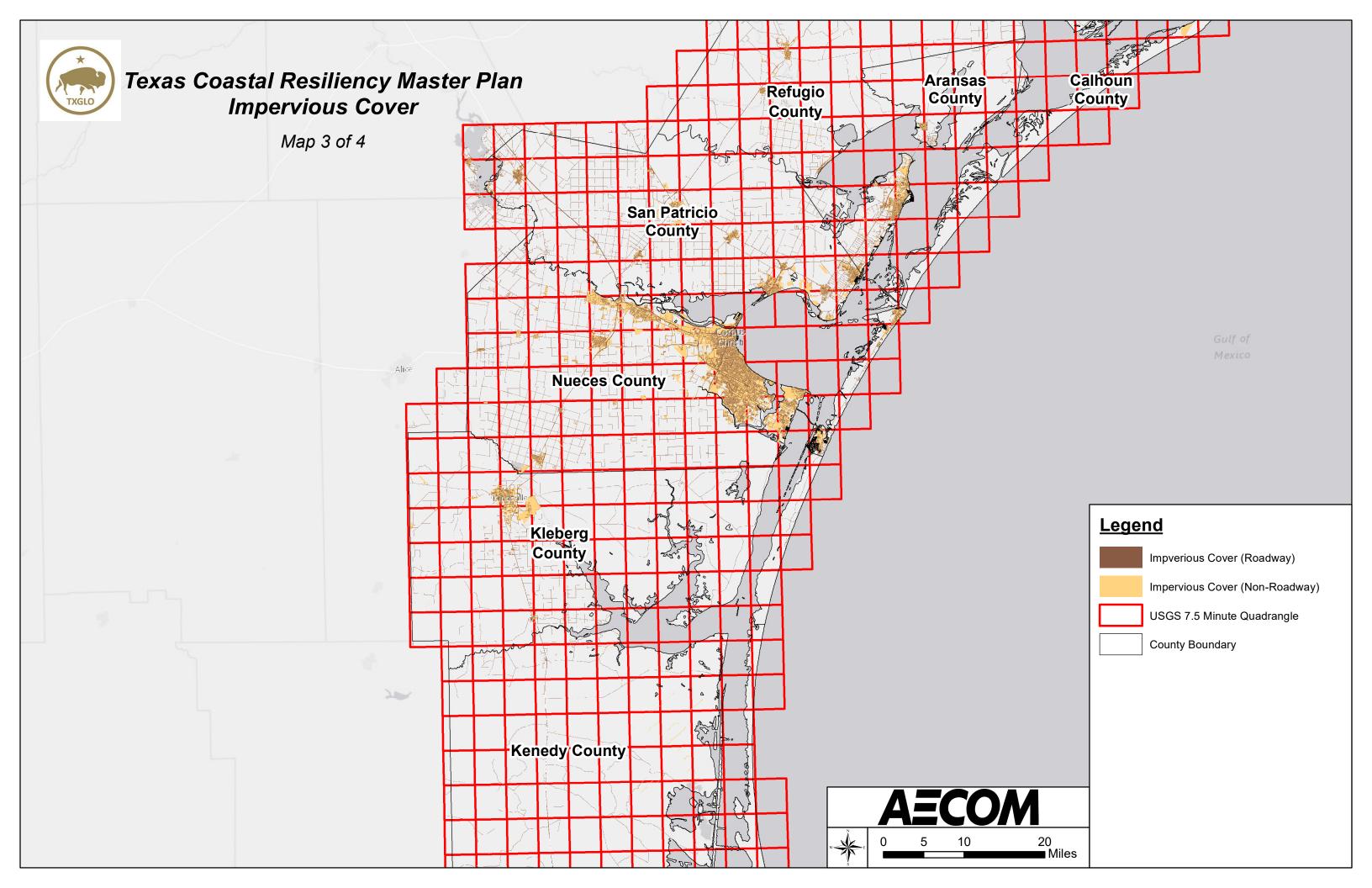
	Ecosystem services	Literature Search for valuation studies specific to the Texas Coast –	Literature Search for valuation studies specific to the Texas Coast (region 1)	Literature Search for valuation studies specific to the whole	AECOM 2018 Tech Memo: Ecosystem Service Valuations	
Habitat Type	provided	Region 3	(US\$ 2019/ha/per year)	Texas Coast \$6,793 (annual	(US \$2018/acre/year )	Source for value estimates:
				average/acre/year in		
Coastal wetlands	Surge protection	NONE	-	US\$2019)	\$6,700	Costanza et al. 2008
Coastal wetlands	Surge protection	NONE	\$8,389.50			Ko et al. 2007
Coastal wetlands	Surge protection	NONE	\$5,625.92			Feagin et al. 2010
Coastal wetlands	Habitat (Water Quality)	NONE	-		\$200	Woodward and Wui 2001
				\$4.38/ha for US\$ 2012;		
Coastal wetlands	Habitat (fisheries)			(\$1.77/ac for US\$ 2012)		Freeman 1991

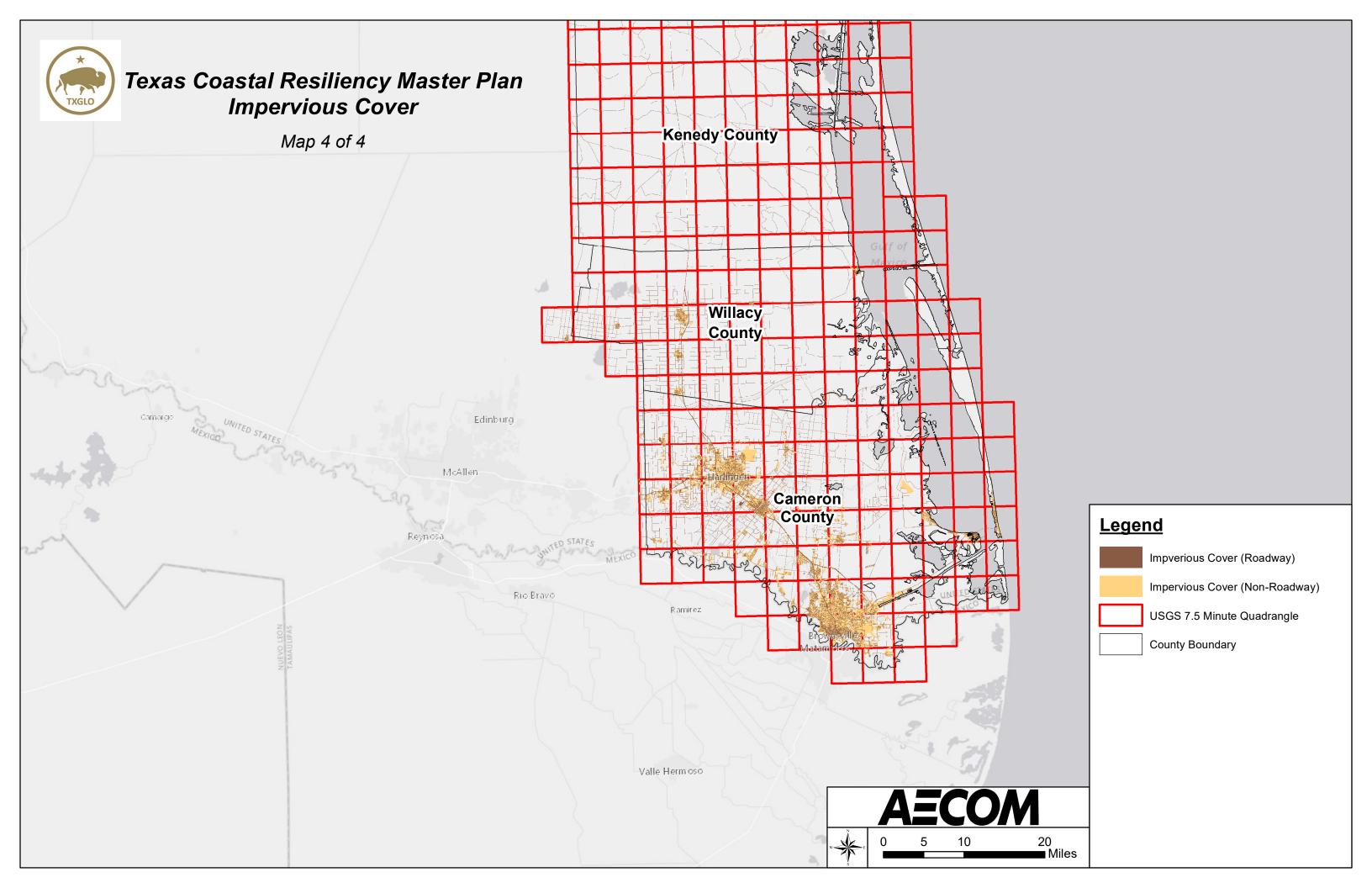
Case Study 2: Galv	veston Island West of Seawall to	8 Mile Road Beach N	Nourishment Region 1			
Habitat Type Beach	Ecosystem services provided  Storm protection	Literature Search for valuation studies specific to the Texas Coast – Region 1	Literature Search for valuation studies specific to the Texas Coast – Region 3	Literature Search for valuation studies specific to the whole Texas Coast (US\$ 2019/ha/per year)	AECOM 2018 Tech Memo: Ecosystem Service Valuations (US \$2018/acre/year) \$33,600 (applies to beaches and dunes that protect property)	Source for value estimates: Mendoza-Gonzalez et al. 2012 (Gulf of Mexico, Mexican Coastline)
			\$141.4 million/6.89km2/year		process proposity,	,
Beach	Storm protection	NONE	in US\$2013 (Region 3) = \$83,078,73/acre			Taylor et al. 2015 Liu et al. 2010 (Meta-
Beach	Recreation and aesthetics	NONE			\$19,400	analysis for NJ coast)
Beach	Tourism (recreation)	NONE		\$5,370.64 (US\$ 2019 /per person /per year) \$38,34 per person/per		Freeman 1995 Parsons and Kang 2007
Beach	Tourism (recreation)	NONE		visit in US\$2019		(Region 3)

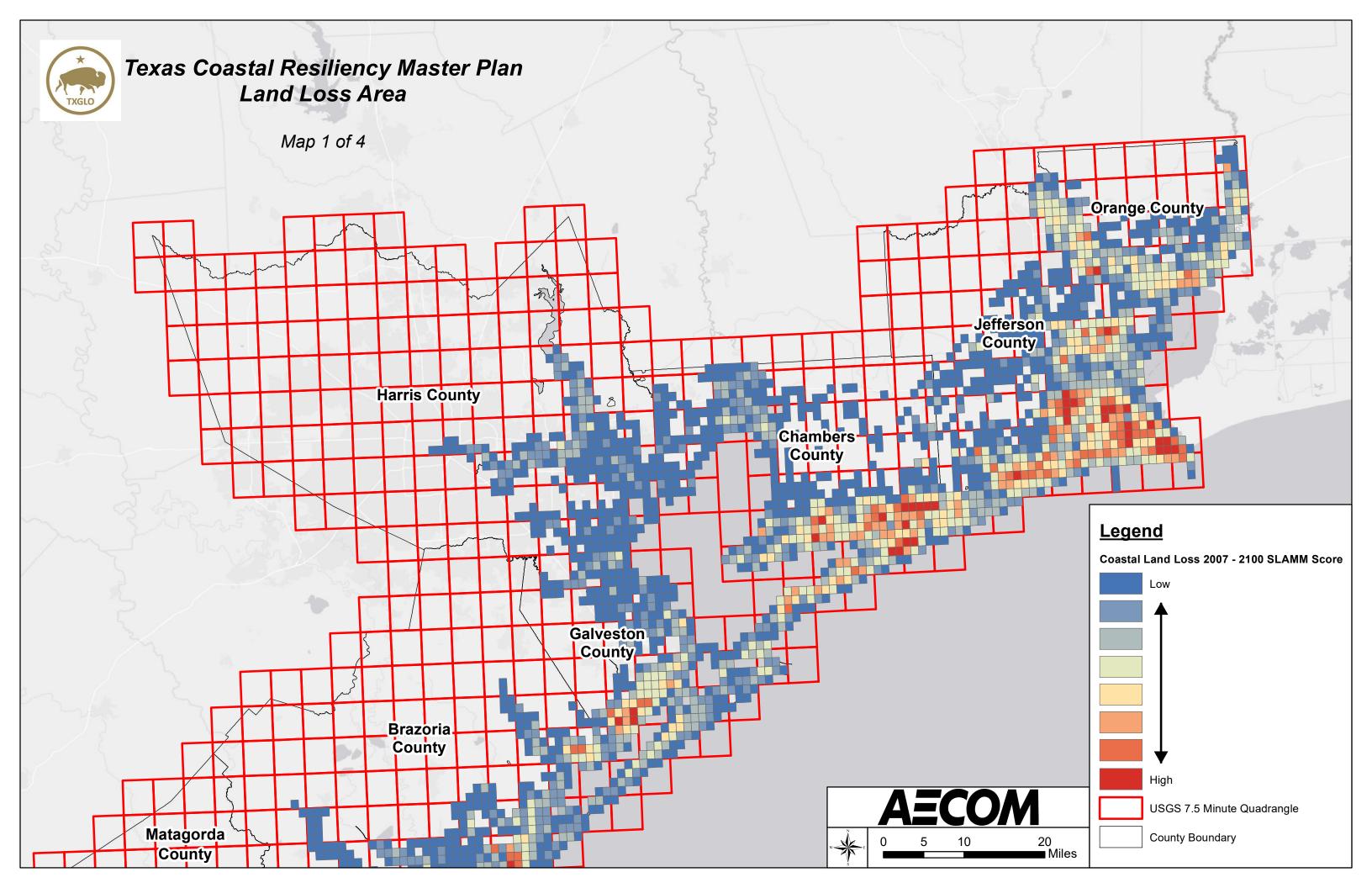
# Appendix C Background Data for Risk Index Map

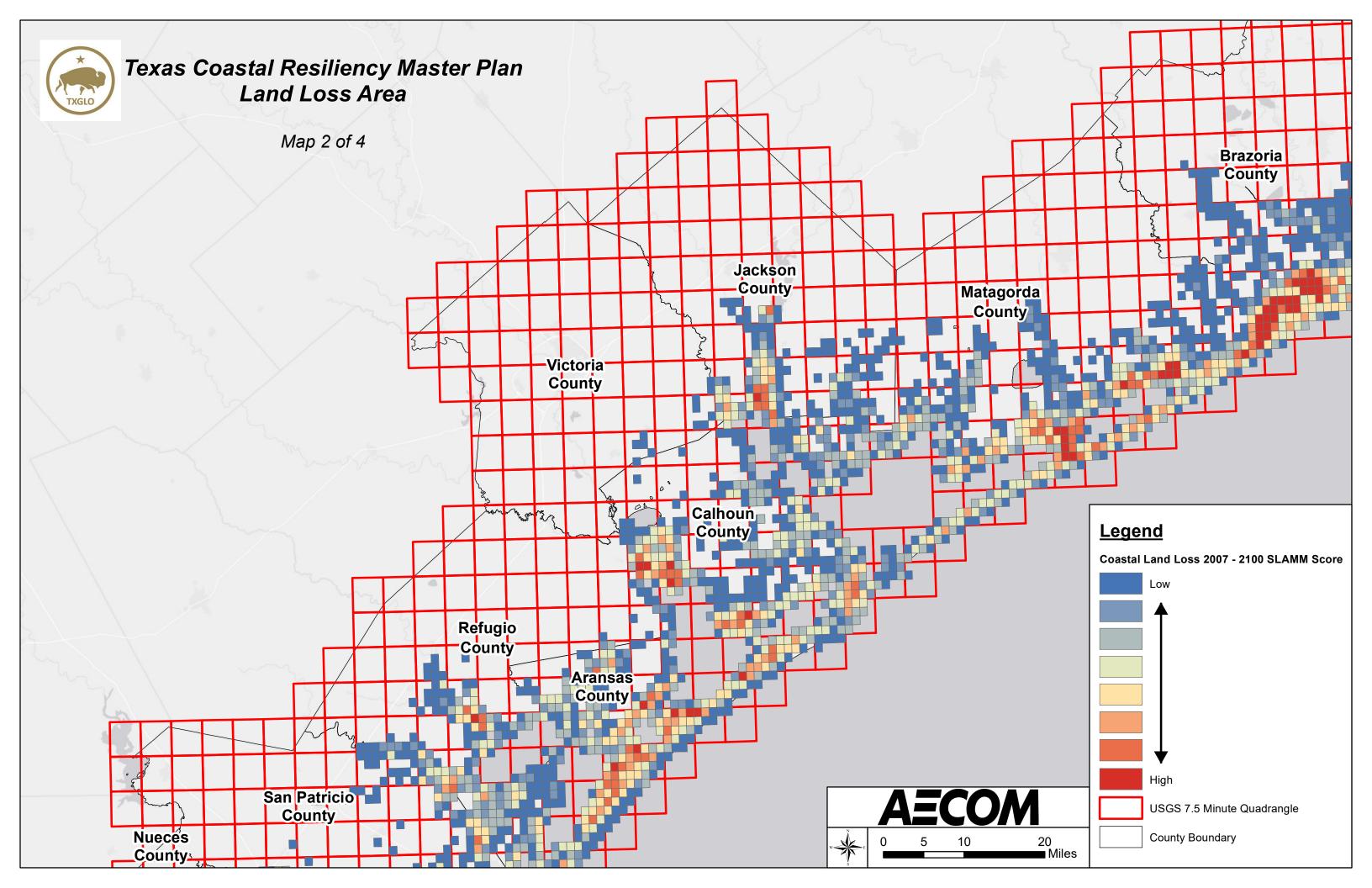


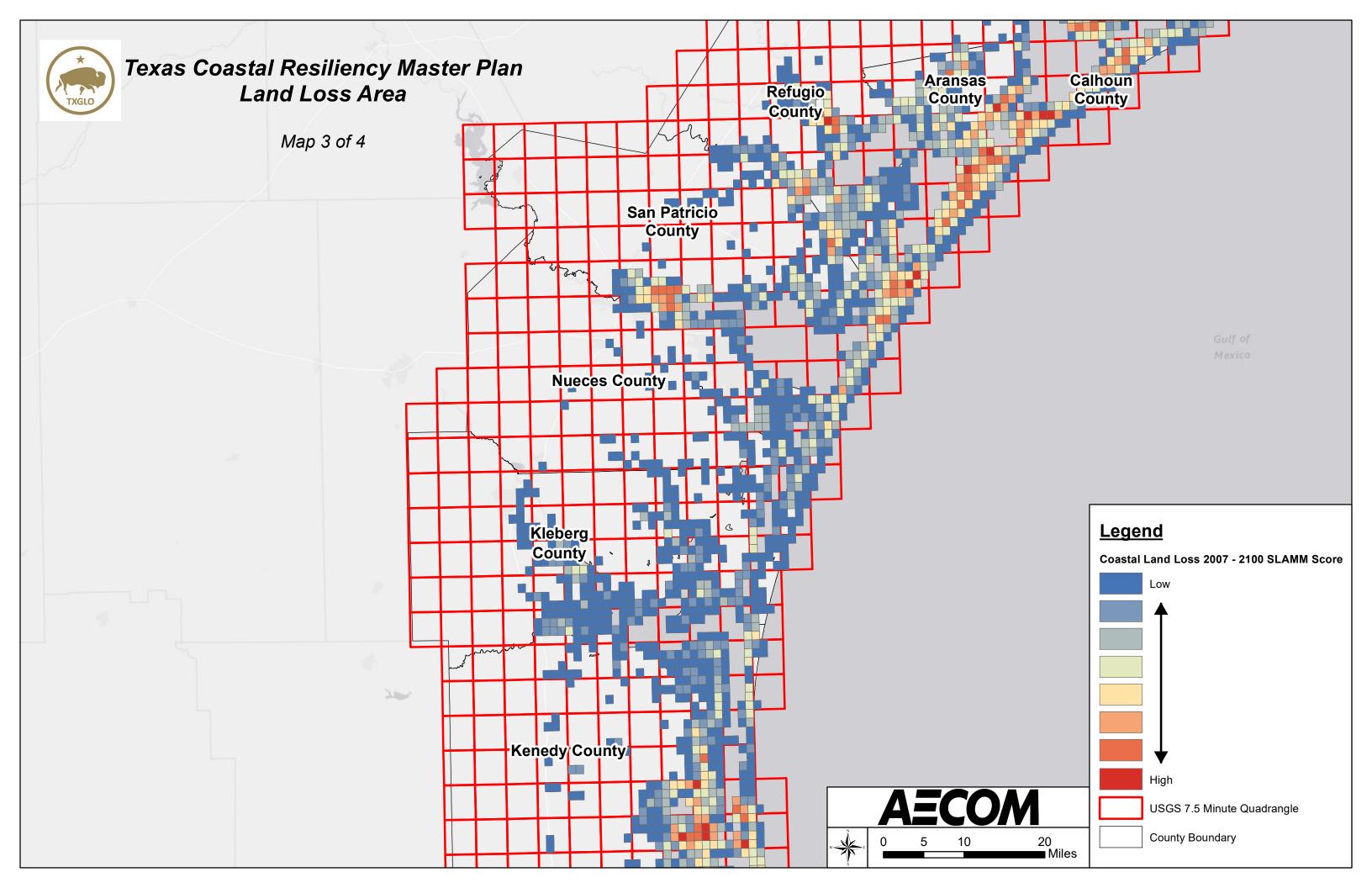


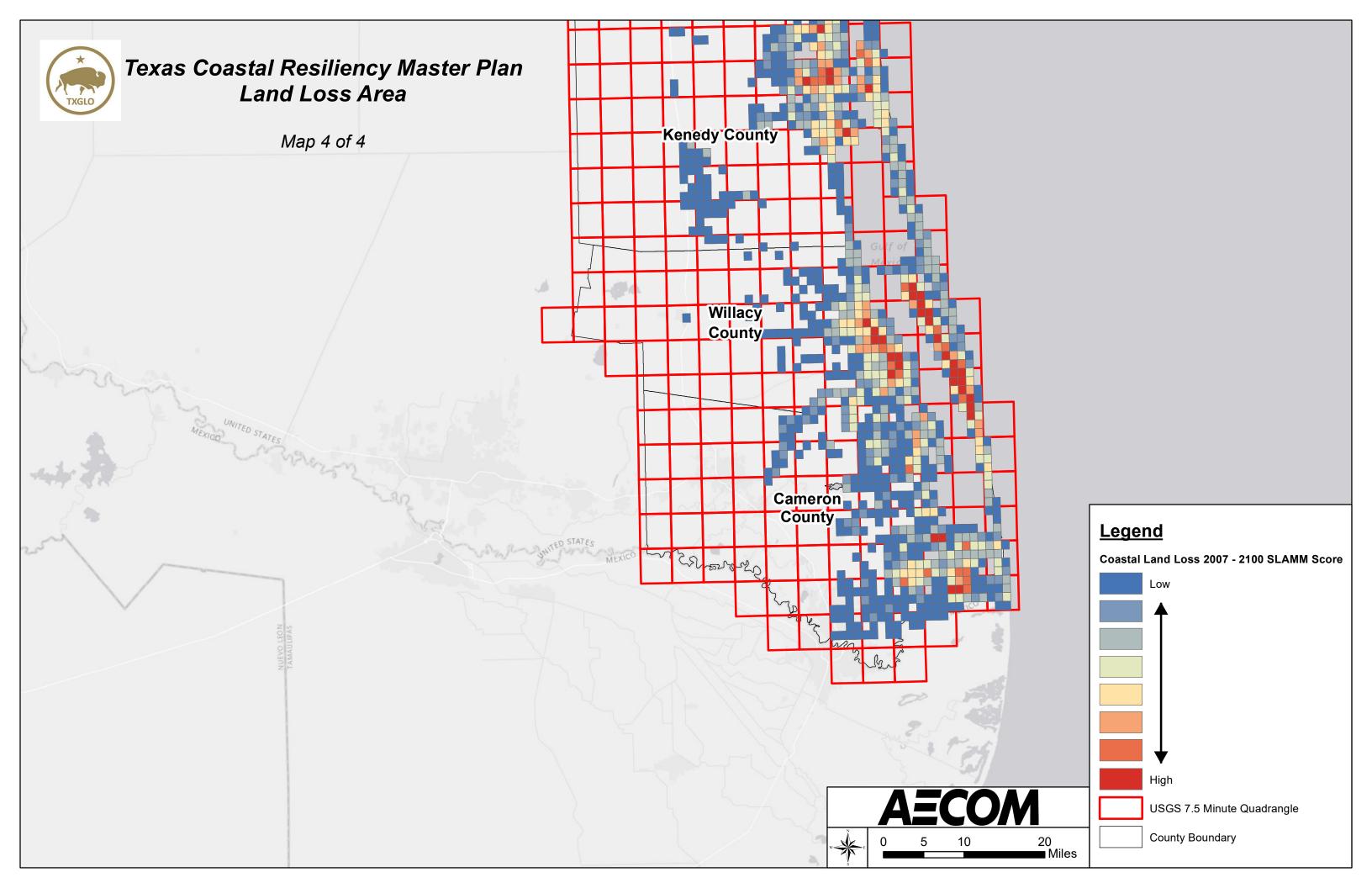


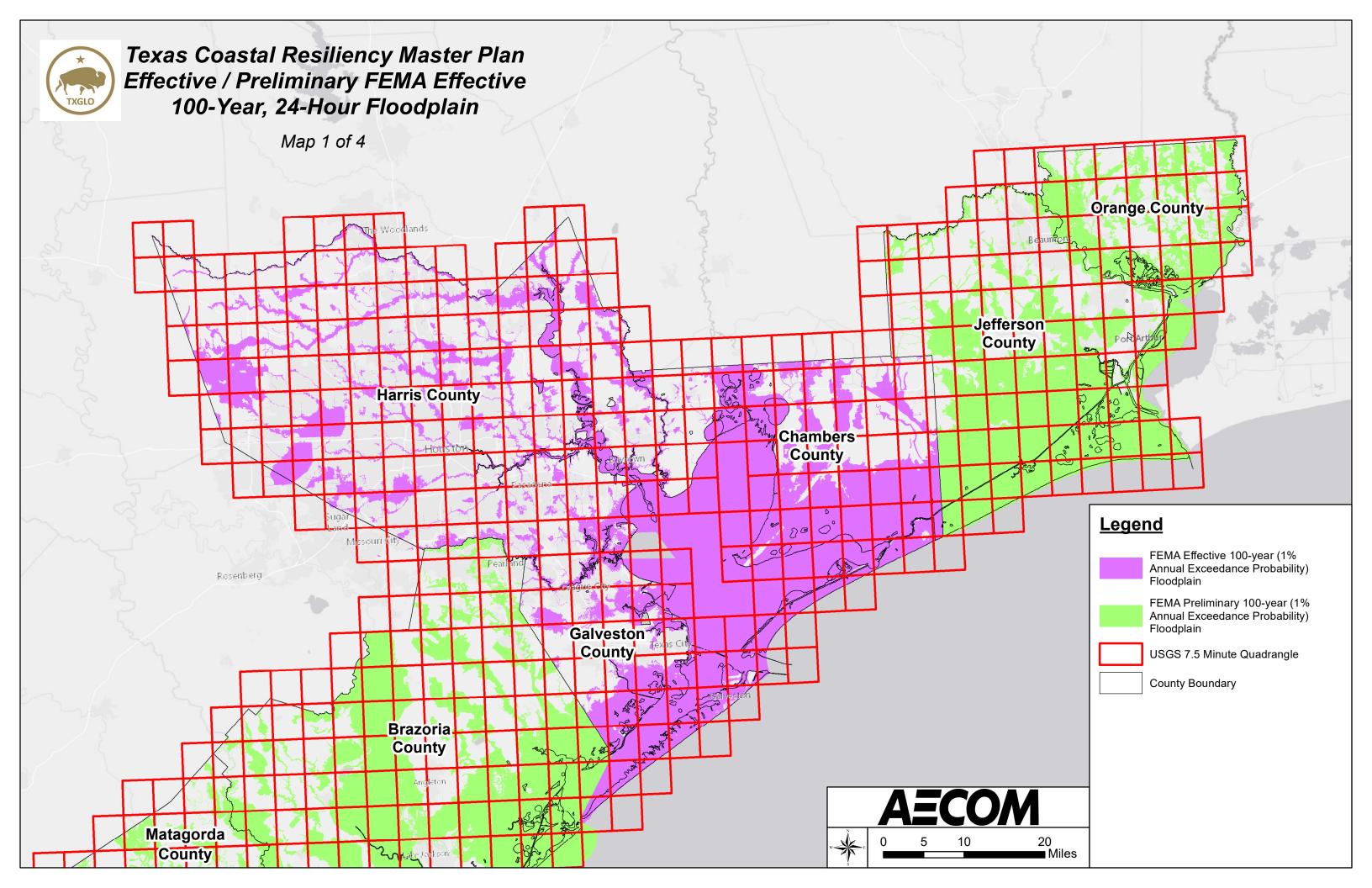


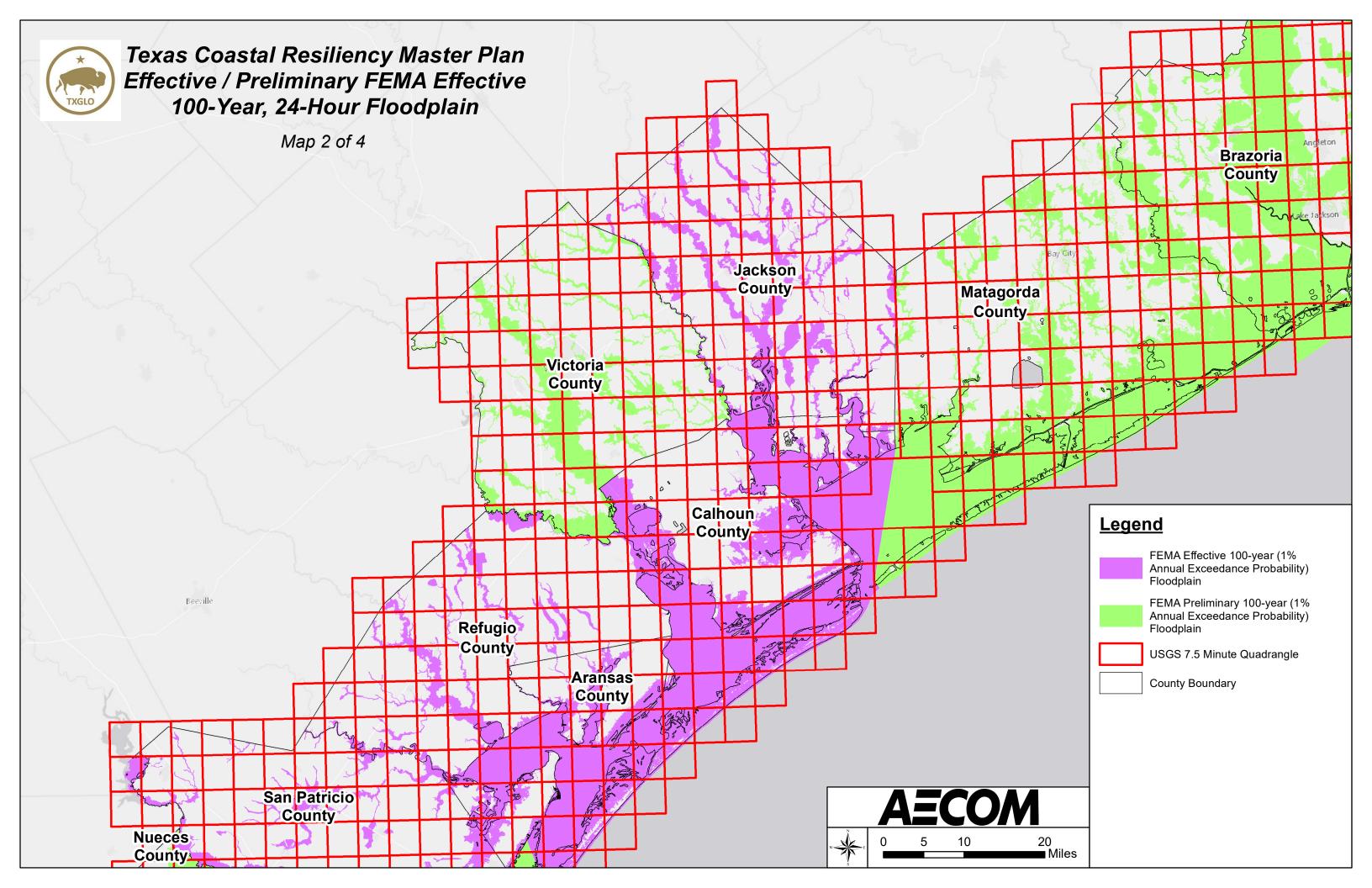


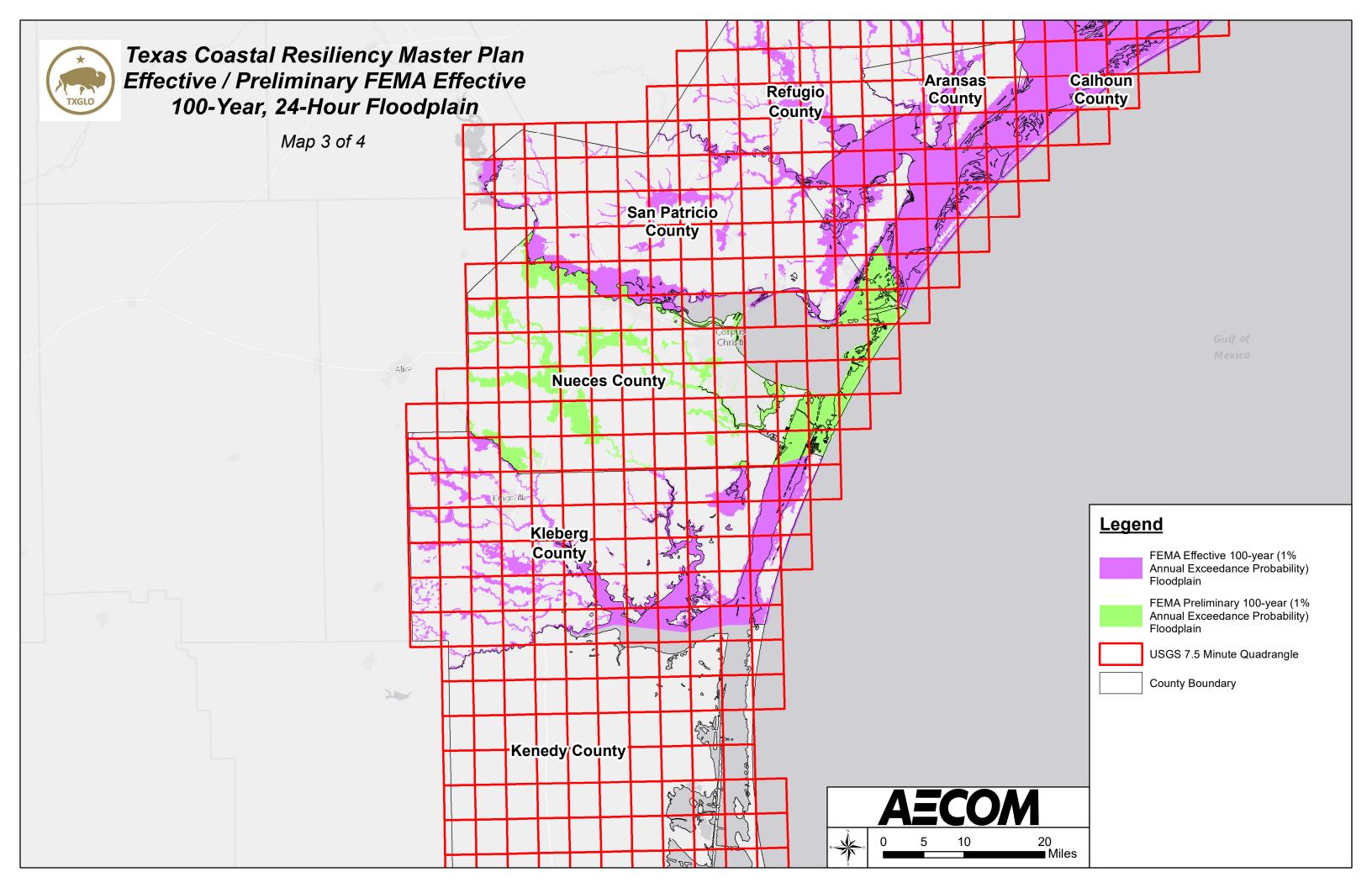


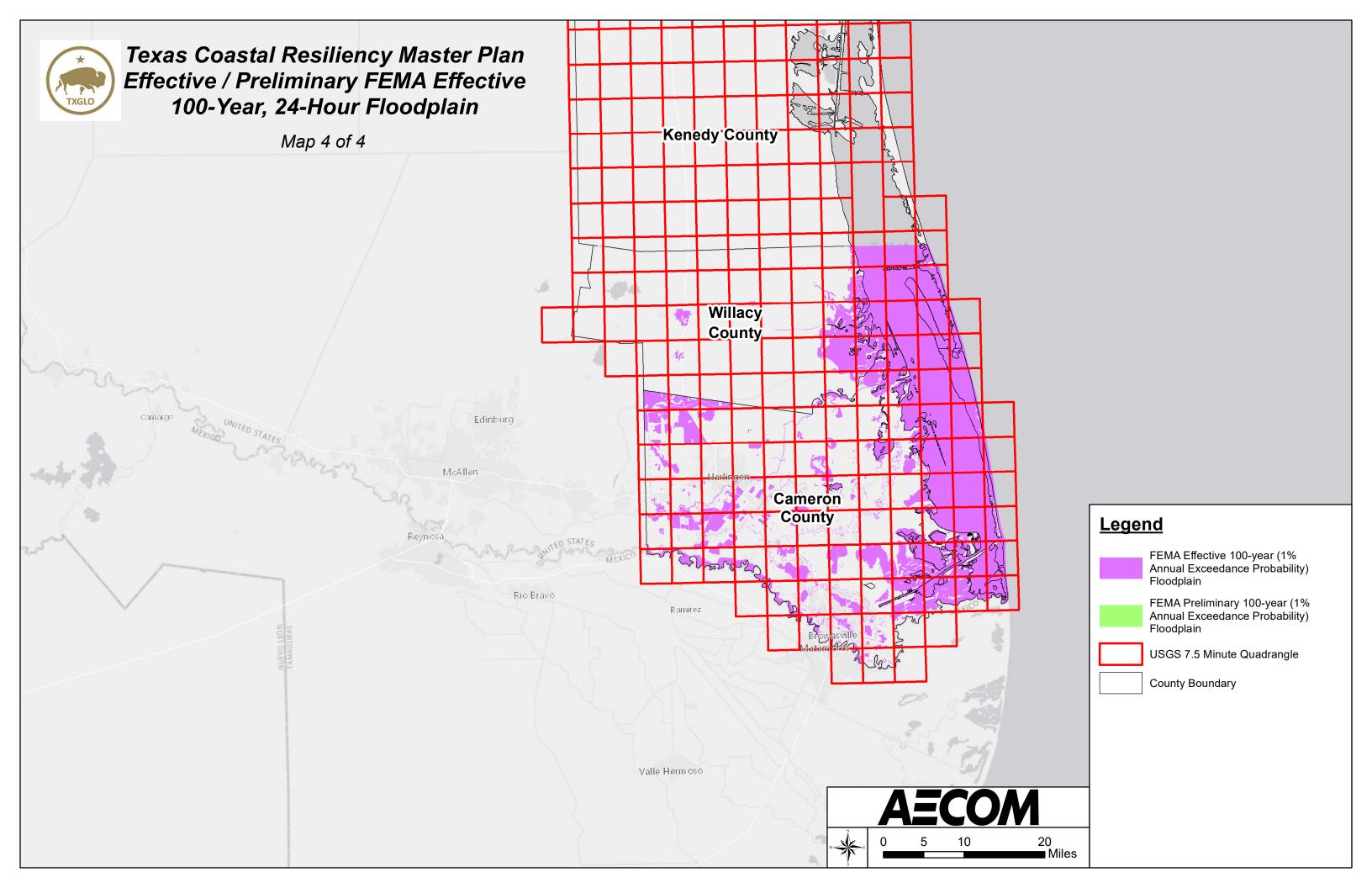


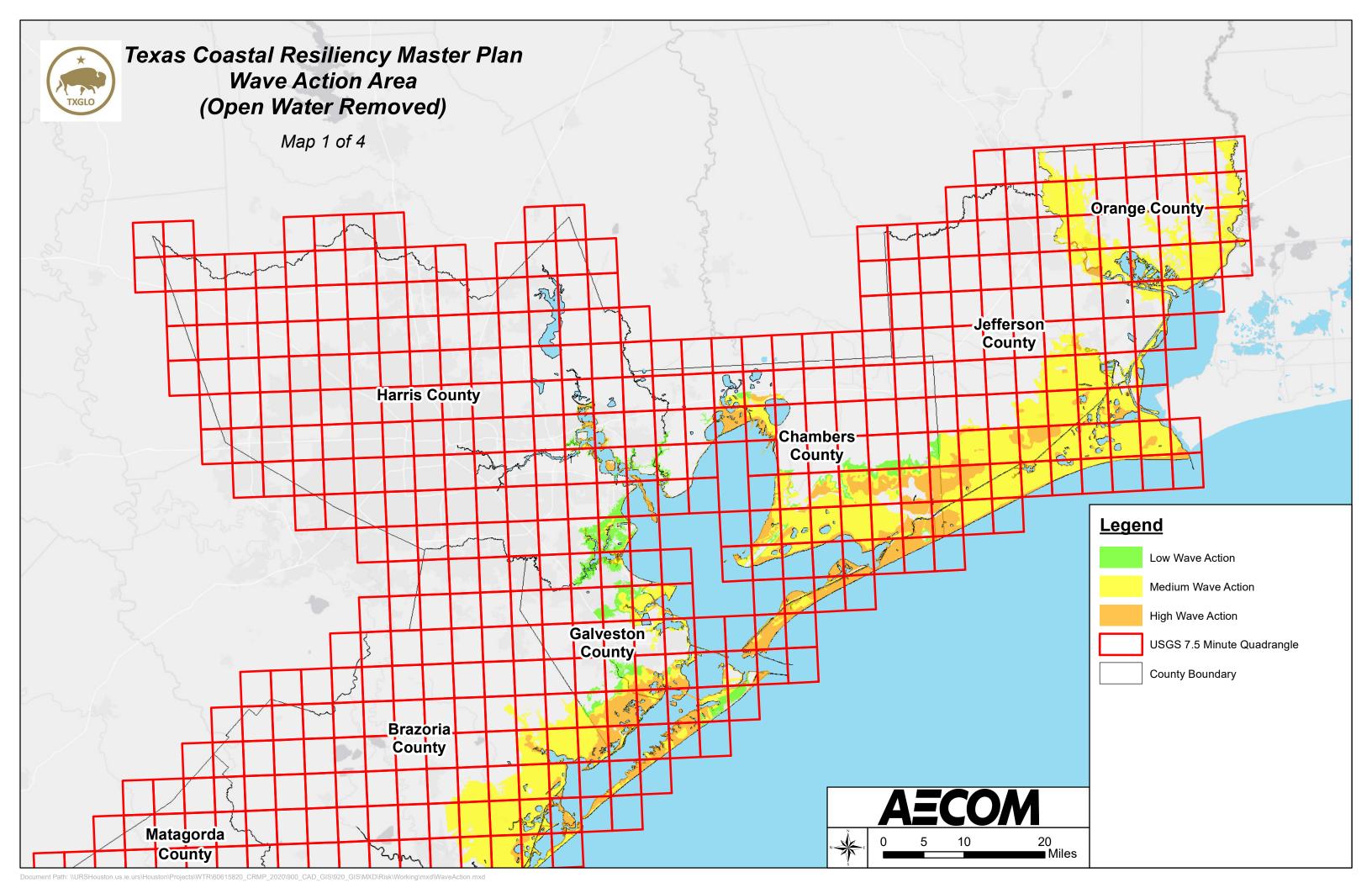


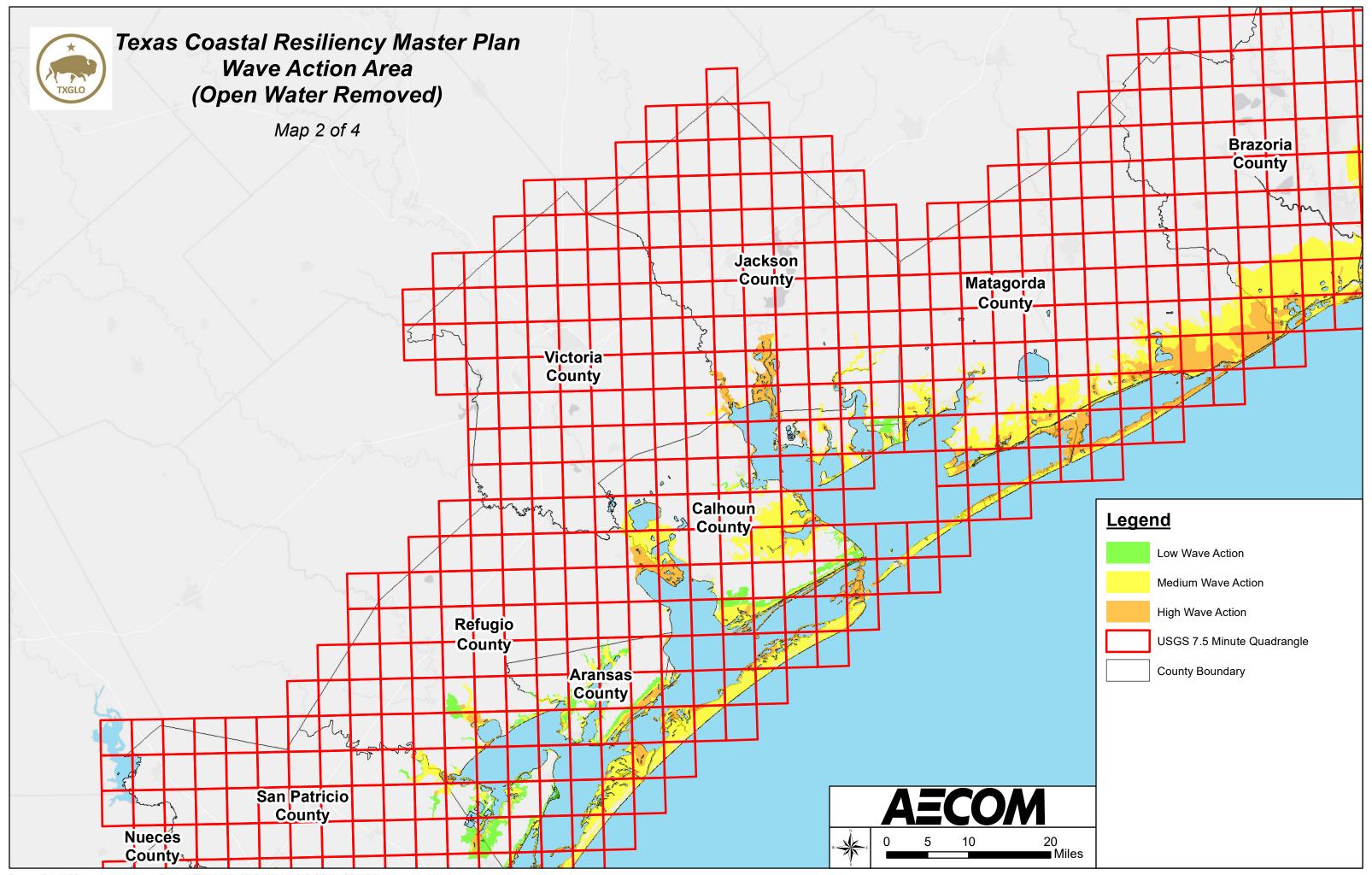


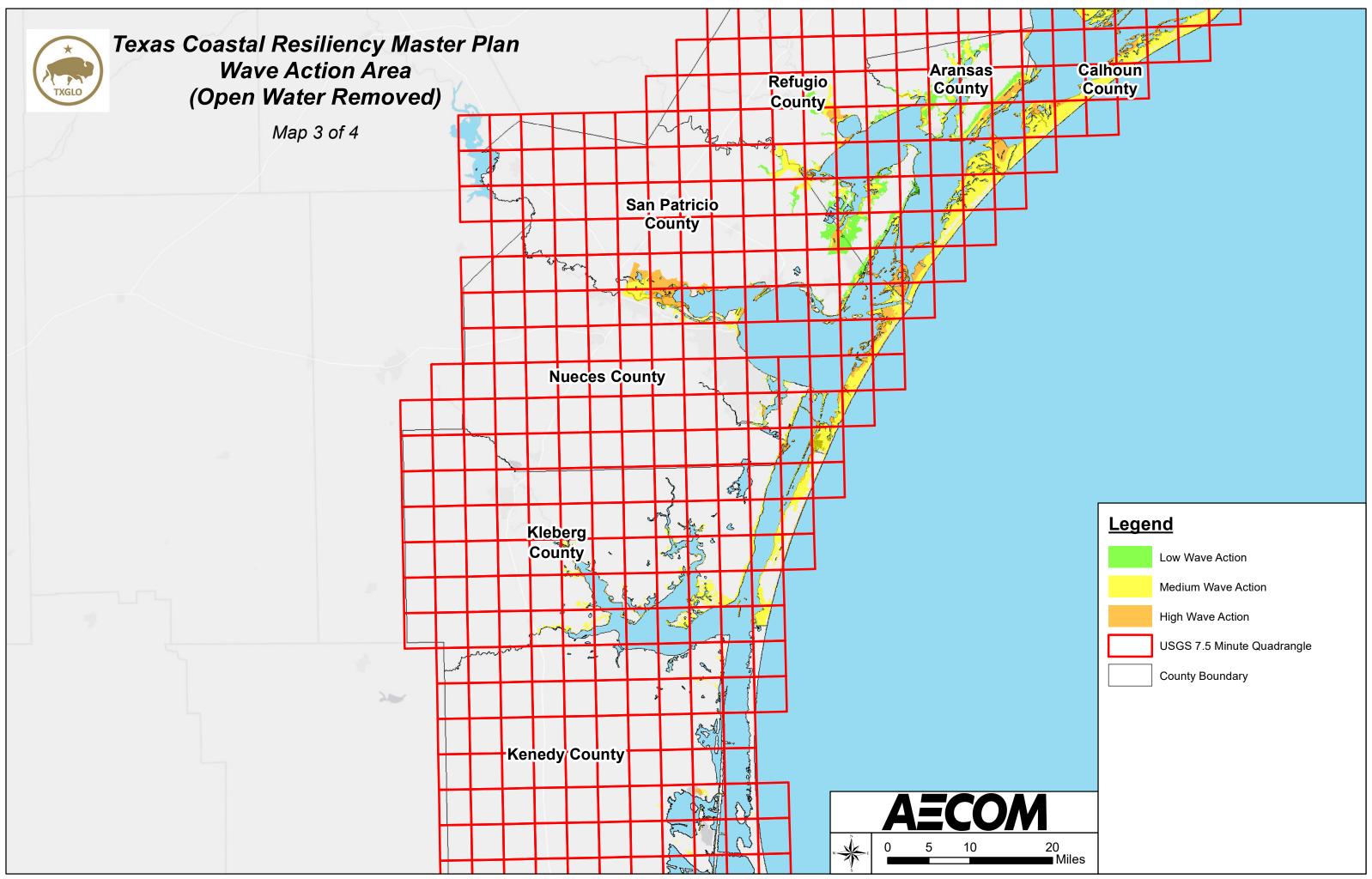


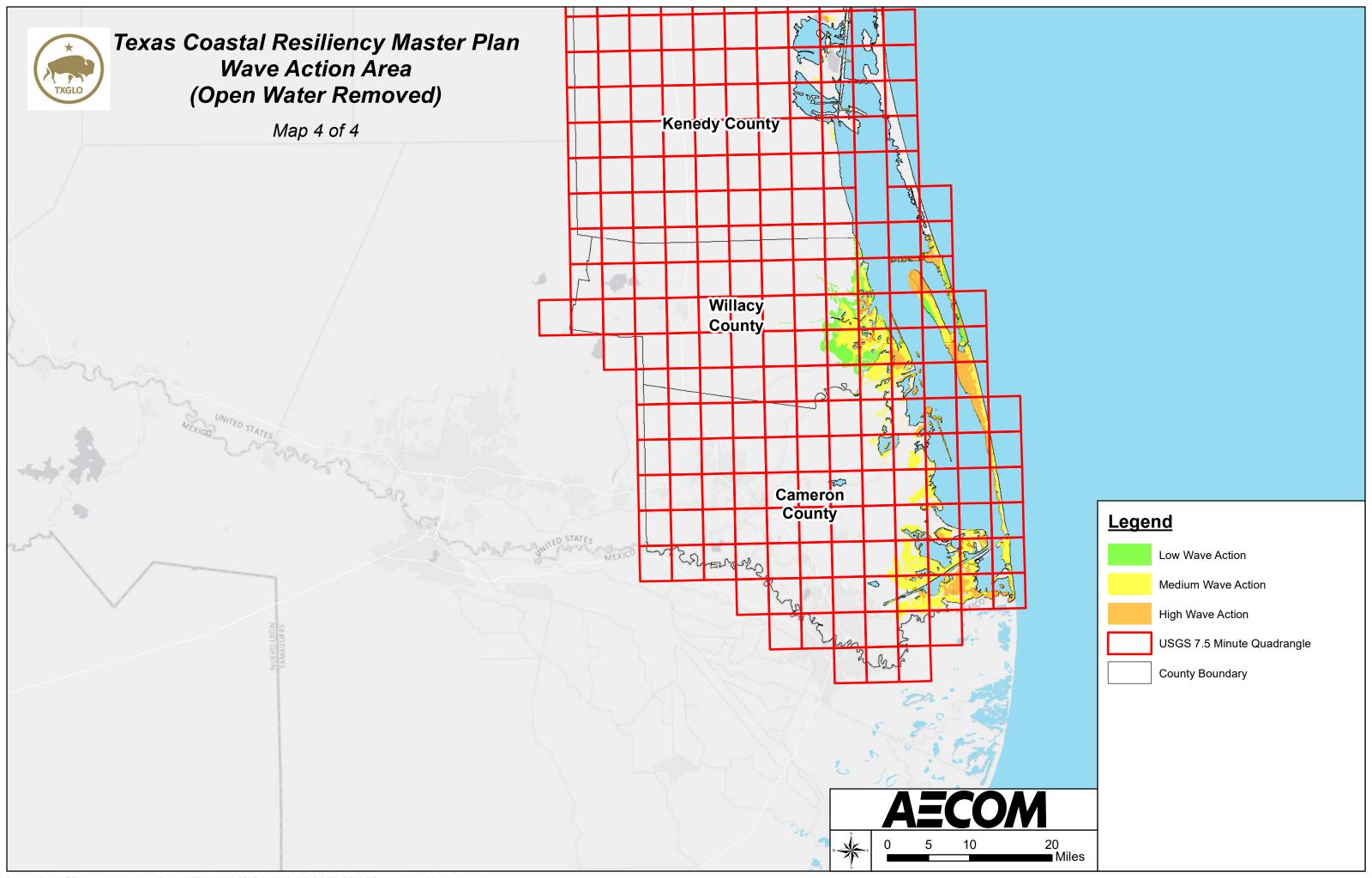












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